The California Water Sustainability Indicators Framework

DRAFT

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I. Executive Summary

Measuring environmental, social, and economic conditions and influences on these conditions is an important part of knowledge-building and adaptive management. The California Water Sustainability Indicators Framework (hereafter "Framework"), being developed as part of the California Water Plan (CWP) Update 2013, brings together water sustainability indicators that can inform us about water system conditions and their relations to ecosystems, social systems, and economic systems. The evaluation of the selected sustainability indicators is anticipated to reveal how our actions or inaction can degrade or improve conditions that lead to water sustainability. The Framework is built around both statements of intent (e.g., objectives) and themes (e.g., water quality). Reporting indicator condition is based upon the principle of measuring how far a current condition is from a desired condition. The Framework is intended to support reporting of indicators to a wide array of water and environmental stakeholders, the public, and decision makers to build knowledge and to enhance adaptive decision-making and policy change.

The basis of the Framework is an overall vision for water-related sustainability indicators for California, including an understanding of sustainability, indicators, and related terms. Based on a generally agreed-upon vision, the proposed Framework operates through a series of inter-related steps, beginning with defining objectives and ending with reporting conditions relative to sustainability targets. Each step generally follows the previous step and completing all steps is necessary for a full evaluation of water resources sustainability. Ultimately, the Framework informs us how well we are sustaining the natural, social, and economic systems that we depend upon and how we can improve degraded conditions.

Why Are We Doing This?

The mission of the California Department of Water Resources (DWR) is to manage the water systems of California, in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. To fulfill its mission, DWR prepares the California Water Plan Update, Bulletin 160 (Water Plan). Providing a comprehensive statewide water reporting and management framework, the Water Plan is the State's strategic plan for developing and managing water resources statewide. Mandated by the California Water Code (Section 10005 et seq.) and updated every five years, the Water Plan sets forth a blueprint for water managers, legislators, and the public to consider options and make decisions regarding California's water future.

With a growing recognition that California's water systems are finite, and faced with climate change, growing population, and more stringent environmental requirements, decision-makers, water managers, and planners are becoming increasingly aware of the need to sustainably manage for the long-term. In the Water Plan Updates 2005 and 2009, DWR refocused attention on the long-term sustainability of California's water systems and ecosystems in light of current water management practices and expected future changes. However, one recurring question from stakeholders has been, “How can we ascertain that the objectives of the Water Plan and the associated resource management strategies would lead to sustainable water use and supply for the State and its various hydrologic regions?”

To respond to the above concern, one of the guiding principles established for decision-making in the California Water Plan Update 2009 was: “Determine values for economic, environmental, and social benefits, costs, and tradeoffs to base investment decisions on sustainability indicators.” However, there are major impediments to address the state’s water sustainability using sustainability indicators. These include: inconsistent terminologies and definitions used; absence of a systematic analytic framework and methodologies for quantification of water sustainability indicators; and a potential lack of data to undertake the appropriate analysis to assess sustainability of water resources through the development and on-going tracking of a set of sustainability indicators. As part of the Water Plan Update 2013, DWR has initiated a process to develop a framework and a set of preliminary sustainability indicators. We anticipate that the developed framework will help us identify, compute, and evaluate a set of relevant sustainability indicators that would help monitor progress towards sustainability of natural and human water systems.

Who Are We Working With?

The core team of DWR, UC Davis, and USEPA scientists envisions a stakeholder driven, collaborative, and transparent process for reaching agreement on a water sustainability vision through work team activities, meetings, workshops, and outreach. We also want to ensure that the Framework and analysis developed as part of this project have solid scientific and technical underpinnings and are defensible and well accepted by the peers in the field. We anticipate using the Water Plan’s extensive stakeholder participation processes for this purpose:

- DWR and partner agencies work teams – DWR staff work with USEPA and other agency staff and University of California, Davis technical experts.
- Water Plan’s Statewide Water Analysis Network – convene and connect with leading experts to ground-truth the technical analyses.
- Sustainable Water Resources Roundtable - Bring in the latest perspectives on the methods and practices related to water resources sustainability.
- State Agency Steering Committee - weigh in overall State government coordination and perspective in the water planning process.
- Water Plan Public Advisory Committee – access views of a broad stakeholder group.
- Regional Forums – obtain regional perspective using regional and local relationships through DWR’s Regional Offices, IRWM outreach activities, and Regional Forums.
- Tribal Advisory Committee - involve the California Native American Tribes in the state and regional planning process.
- Federal Agency Network - engage federal agencies in the state water planning process.

What Do We Mean By Sustainability?

The California Water Plan, 2009 Update, included a vision statement laying the foundation for how California can be sustainable in water use and management. The vision is that: *California has healthy watersheds and integrated, reliable, and secure water resources and management systems that: Enhance public health, safety, and quality of life in all its communities; Sustain economic growth, business vitality, and agricultural productivity; and Protect and restore California's unique biological diversity, ecological values, and cultural heritage.*

Generally speaking, "A system that is sustainable, should meet today's needs without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1983). The USEPA defines sustainability as "The satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends." The state of Minnesota adopted this definition of sustainable water use as part of their Water Sustainability Framework, "That which does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs." And there are many other definitions as well.

In order to help meet the vision of the Water Plan, we propose the following definition for sustainability: *Water sustainability for California is the dynamic state of water use and supply in the state and its regions that meets today's needs without compromising the long-term capacity of the natural and human aspects of the water system to meet future needs, considering all three aspects of sustainability - the ecosystem, the social system, and the economic system*.

How Does the Indicators Framework Work?

The Framework is organized into steps corresponding to major procedural endeavors. Completing each step leads to subsequent steps and completing all steps is necessary for a full evaluation of water sustainability.

Step 1 Define water sustainability and related terms
Step 2 Describe the overall vision for sustainability, goals corresponding to the vision, and measurable sustainability objectives; describe themes (e.g., water supply) and system processes
Step 3 Select indicators corresponding to the objectives and covering all themes and processes; define targets for each indicator; describe potential causes of change in indicator condition
Step 4 Collect data for each indicator, maintain and describe data provenance; analyze data according to distance from current state from target state and describe analytical steps; measure trend in condition and significance of trend
Step 5 Describe summary condition and trend in condition in report card; evaluate performance of system sectors
Step 6 Evaluate causes of condition departure from target condition and individual and programmatic actions that could maintain good conditions and repair poor conditions

Step 7 Describe contribution of evaluation to change in knowledge, policy effectiveness, and public education

For the envisioned Framework, we propose to use the structure of a vision- objectives-indicators-metrics nested hierarchy. In the Water Plan Update 2009 there are goals, objectives, guiding principles, and resource management strategies in separate narrative tools directing actions and desired outcomes. The proposed Framework is based upon "water sustainability objectives" and can be used to evaluate whether meeting the goals, objectives, and resource management strategies of the Water Plan leads towards sustainable water use and supply in California. The water sustainability objectives derive their meaning and much of their text from the Water Plan statements of intent, but attempt to make clearer connections with the idea of sustainability across ecosystem, social system, and economic system. A sequence of steps is proposed going from left to right, where vision and objectives drive the selection of indicators, indicator condition is evaluated relative to reference conditions, and indicator conditions are reported to inform knowledge development and policy decisions.

Table 1. Glossary of terms

Term	**Definition**
Objective	Objectives are measurable descriptions of desired outcomes for particular aspects of the system's condition.
Indicator	Indicators are typically qualitative or quantitative parameters that are familiar from monitoring programs (e.g., streamflow), becoming indicators when selected to represent parts of ecological, social, or economic systems.
Index	An index is an aggregation of indicators that may convey a story about a system, or part of a system.
Theme/domain	Themes and domains are types of category and are terms of art referring to large parts of natural or social systems (e.g., landscape condition).
Metric	Metrics are the building blocks of indicators and thus the foundation of condition assessment. Examples include streamflow, groundwater level, native fish population size, and water temperature.

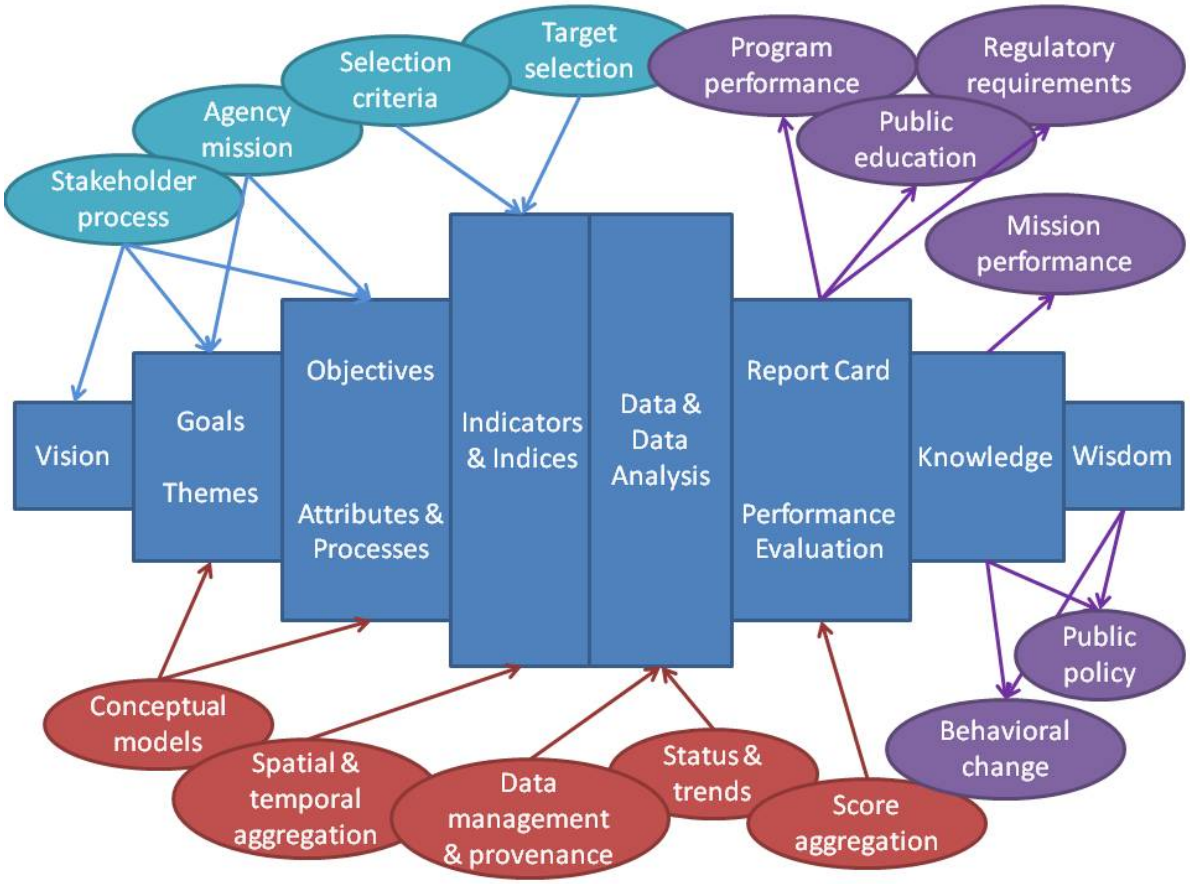

Figure 1 Sustainability Indicator Framework and procedural steps.

Where Are We Going to Implement It?

One anticipated utility of the Framework is that it will provide a toolbox, useful templates, and a set of illustrative examples for IRWM regions to conduct water sustainability analysis for local and regional water management. By utilizing this Framework, local and regional water and other agencies comprising the IRWM regions may be able to improve their sustainability through an evaluation of condition and trends of relevant indicators reflective of their particular needs. The process will also help identify issues and data gaps to inform future data monitoring needs on a local and regional scale to enable better quantification of water sustainability in the future. Similar to the case for the state as a whole, the indicator analysis on a local and regional scale by the IRWM regions is also expected to highlight policy needs for ensuring the local and regional water sustainability.

When Will We Accomplish Each Step?

The timeline for development of the Framework began with the description of objectives and strategies in the 2009 Update. More recently, a team comprising UC Davis, DWR, and USEPA Region 9 scientists has formulated an approach that is consistent with both the best scientific practices for indicator systems and the California Water Plan. By end of July, we hope to release the draft Framework for review by partner agencies and others. By the end of September, we plan to finalize the Framework in preparation for testing it in a region of California. We acknowledge that defining and developing the Framework will be an ongoing, iterative, and evolutionary process. As we continue to receive stakeholder feedback and learn from testing the Framework in a region of California, we will accordingly refine the Framework as part of the Water Plan Update 2013 process.

How Are Indicators Connected to Ecological and Water Footprints

The basic idea of the ecological footprint is that our activities and physical infrastructure measurably affect an area or other portion of ecosystems (the “ecological footprint”). For example, the land-area required to supply an average US resident with food is ~2.4 acres. The irrigation and other water requirements for providing food and other needs can be measured as a volume of water, (the “water footprint”). In the US, the per capita water footprint is 2,480 m^3/yr, the largest in the world (Hoekstra, 2009). These approaches for measuring our effect on different attributes of natural systems rely on a combination of understanding how human endeavors occur in ecological domains and how much of an ecological attribute may be affected. Indicators are a way to measure these endeavors and ecological attributes. This provides a connection between the more traditional world of condition indicators and a comprehensive way of measuring and describing our effects on natural systems.

II. Approach

The California Water Sustainability Indicator Framework is composed of a cycle of process steps that build upon each other. The cycle begins with defining what is meant by sustainability and other terms and completes one cycle by informing policy and decision-making. The process is intended to be part of a cycle of adaptive learning and action. The indicators and the process of developing, analyzing, and interpreting them are not intended to stand alone, so links are described with regional planning, ecosystem services, and water footprint.

II.A Process Steps

Step 1 Sustainability and Other Definitions

Sustainability has many definitions. The USEPA defines sustainability as “The satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends.” The state of Minnesota adopted this definition of sustainable water use as part of their Water Sustainability Framework: “That which does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs.” Sustainability in the context of the Framework is defined as follows: *Water sustainability for California is the dynamic state of water use and supply in the state and its regions that meets today’s needs without compromising the long-term capacity of the natural and human aspects of the water system to meet future needs, considering all three aspects of sustainability - the ecosystem, the social system, and the economic system*.

Step 2 Water Sustainability Vision, Goals, and Objectives

Society expresses its intent through a variety of mechanisms, including policies, stakeholder goals, etc. Social intent is an important organizing principle for reporting conditions and planning for sustainability. The California Water Plan (CWP) vision statement expresses the overall intent of the Plan in a very general way. Because other statewide plans express intent for actions within their spheres of responsibility (e.g., the California Transportation Plan), an alignment of vision statements is an important activity. This is not the same as developing a common vision, so much as a coordination of intent among public entities and other stakeholders.

Goals and Objectives

Goals are often narrower expressions of intent than vision statements and describe the desired outcome of a system or set of practices. Goals are often broad statements, sometimes with several possible pathways to the outcome. The term “objectives” is often used in the same way as the term “goals”; more often objectives are intended to convey a more exact and measurable desired outcome. An example of a goal from the 2009 California Water Plan (CWP) is “Water resource and land use planners make informed and collaborative decisions and implement integrated actions to increase water supply reliability, use water more efficiently, protect water quality, improve flood protection, promote environmental stewardship, and ensure environmental justice in light of drivers of change and catastrophic events.” A common structure for these systems is a vision-goals-objectives-indicators-metrics nested hierarchy (see Appendix C for global examples). The 2009 CWP does not have this structure. Each list of goals, objectives, guiding principles, and resource management strategies are separate narrative tools directing actions and desired outcomes. The Sustainability Indicators Framework is based upon proposed “sustainability objectives” (table 2). The objectives were derived primarily from the language and intent expressed in the Resource Management Strategies from the 2009 Update. The RMS were used because they provided the most detail and clearest statements of intent in the Plan, which aids in the development of corresponding indicators, which are in turn used to measure condition and performance of social and natural systems affected by the Plan. The CWP Objectives were also referred to, in order to ensure consistency with the several ways that the Plan describes sustainable management of water. The sustainability objectives can be used to evaluate progress toward meeting the principles, goals, and vision of the CWP. In order to do this, an intentional series of relationships would need to be established among the goals, objectives, strategies and principles. These sustainability objectives derive their meaning and much of their text from the 2009 statements of intent, but they make clearer connections with the idea of sustainability across environmental, economic, and equity considerations (the 3 E’s). Implementing the objectives will depend upon interaction with impacted communities and tribes in order to ensure equity across all objectives.

Objectives (CWP, 2009)

1. Expand integrated regional water management
2. Use and reuse water more efficiently
3. Expand conjunctive management of multiple supplies
4. Protect surface water and groundwater quality
5. Expand environmental stewardship
6. Practice integrated flood management
7. Manage a sustainable California Delta
8. Prepare prevention, response, and recovery plans
9. Reduce energy consumption of water systems and uses
10. Improve data and analysis for decision-making
11. Invest in new water technology
12. Improve tribal water and natural resources
13. Ensure equitable distribution of benefits

Table 2. Proposed sustainability objectives for the California Water Plan, Update 2013.

Proposed Sustainability Objectives	Relationship to Water Plan 2009
1. Improve water use efficiency, increase water recycling,	CWP Objective 2, 9; RMS

and increase water conservation in order to improve water supply reliability, reduce energy demand, and restore and maintain aquatic ecosystems and processes.	Reduce demand
2. Improve regional water movement operations and efficiency and investigate new water technologies to contribute to social and ecological beneficial uses and reduce impacts associated with inter-basin water transfers.	CWP Objective 1, 2, 7, 11, RMS Operational efficiency
3. Increase conjunctive management of new and recycled water from multiple sources to increase quantity, quality, and reliability of drinking water, irrigation water, and in-stream flows.	CWP Objective 3, 12, 13; RMS Increase water supply
4. Protect and restore surface water and groundwater quality and the natural systems that maintain these services in order to safeguard human and environmental health and secure California water supplies.	CWP Objective 4; RMS on water quality; chapter 4 discussion of water quality sustainability indicators
5. Practice, promote, improve, and expand environmental stewardship to protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes.	CWP Objective 5, 12, 13; RMS Natural Resources
6. Integrate flood risk management with other water and land management and restoration activities.	CWP Objective 1, 6, 12, 13; RMS Improve flood
7. Improve and expand monitoring, data management, and analysis to support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water resources management systems.	CWP Objective 10; various RMSs; CWP Vol. 1 Chapter 6 Integrated Data and Analysis

Step 3 Indicators and Target Selection

Indicators provide the connection between statements of intent and measurable aspects of natural and human systems. Because of the importance of the indicators in determining findings and basing decisions, the indicators themselves should be carefully chosen. Similarly, target or reference conditions against which to compare current conditions for each indicator should be transparently and carefully chosen.

Indicator Selection

Evaluating progress toward measurable objectives is the primary intent of the Framework. To carry this out, representative and practicable indicators are selected and evaluated over time. Explicit criteria should be used to select indicators to ensure that the resulting evaluation is robust and usable in decision-making (Appendix B). These criteria include: 1) availability of high-quality data; 2) long-term data affordability; 3) system representation; 4) sensitivity to change over time; 5) independence of indicators from one another; and 6) supports management decisions and actions. Although all are important criteria, it is possible that a really good indicator does not meet all criteria; however, each indicator should meet most of these criteria.

There are thousands of possible indicators to choose from to describe how well systems are performing relative to sustainability goals and objectives. Developing this Framework included the investigation of several dozen indicator systems from around the world (summarized in Appendix C). Candidate indicators from these global systems and from more familiar programs in California were evaluated relative to the indicator selection criteria (Appendix B) and are listed in Appendix D. The following table provides illustrative examples of the candidate indicators.

Table 3. Examples of candidate California Water Sustainability Indicators

Sustainability Objective	Related CWP Objective and RMS	Example Indicators	Relevance to Sustainability Objective
SO 1	CWP Objective 2, 9; RMS Reduce demand	Energy required per unit of clean drinking water	Reduce energy demand for providing water
		Average water use per household/capita, 20% reduction by 2020	Increase water conservation
		Sufficient flows and timing of flows for maintaining historically-present native aquatic fauna	Restore and maintain native ecosystems
SO 2	CWP Objective 1, 2, 7, 11, RMS Operational efficiency	Distance traveled for units of drinking and irrigation water	Improve efficiency of water movement
		Infrastructure reliability	Improve water movement operations
SO 3	CWP Objective 3, 12, 13; RMS Increase water supply	Percentage of irrigated area that is in water-stressed areas	Increase quantity and reliability of irrigation water
		Net recharge or withdrawals	Increase conjunctive management of multiple sources
SO 4	CWP Objective 4; RMS on water quality; CWP chapter 4 water quality indicators	Ratio of observed to expected native aquatic species	Protect and restore water quality for environmental health
		Surface-water Water Quality Index	Surface water quality to safeguard human and environmental health
		Groundwater Water Quality Index	Ground water quality to safeguard human health

SO 5	CWP Objective 5, 12, 13; RMS Natural Resources	Percentage of key stewardship and water conservation actions that are implemented both during and after planning	Practice environmental stewardship to enhance environmental conditions
		Proportion of streams monitored periodically	Practice environmental stewardship
SO 6	CWP Objective 1, 6, 12, 13; RMS Improve flood	Proportion of new construction with reduced paved surface and water conservation	Integrate flood risk management with water and land management
		Proportion of floodplain per reach in conservation	Integrate flood risk management with restoration
SO 7	CWP Objective 10; various RMSs; CWP Vol. 1 Chapter 6 Integrated Data and Analysis	Data sharing, standardization, and distribution among disparate entities	Improve data management to support integrated regional water management
		System supports adaptation and resilience to climate change	Support decision-making in light of uncertainty

Indicator Targets

Comparing indicator condition against a reference value is a critical requirement for using indicators to inform condition assessments. This value could be changed in future assessments, with corresponding revisions of past scores. This reference value could be an historical condition, a desired future condition, a legal threshold, or some other value. It provides the context for interpreting indicator results — a number against which current status and trends can be compared. For instance, a high water temperature or an increasing trend in water temperature only tells us something meaningful about the risk of this condition to fish if we know at what temperature fish will be adversely affected, and whether the current trend is moving closer to or further away from that temperature threshold. A reference value is a quantity/value of an indicator that reflects some threshold, desired goal or target, or historic and/or pristine condition, according to what is most meaningful for the assessment and reporting purpose, and supported by science. The selection of reference values is as important as the selection of the indicator itself because, without this baseline, it is difficult to assess the magnitude of change objectively, whether the magnitude of change is important, or if any efforts at improving conditions are succeeding (National Research Council, 2000).

Step 4 Data Provenance and Analysis

This step is the data collection, data management, and data analysis step in the Framework. Data provenance is a term describing the path of data into the analytical framework, including where the data came from, what was done with it, and what was found out.

Indicator Data

Most indicators are chosen because information is available or is likely to become available to inform evaluation. Quantitative indicators are typically parameters that are familiar from monitoring programs (e.g., # spawning salmon) that become indicators when they are chosen to represent important parts of social-ecological systems. Because of the special role that indicators play in public education and decision-making, data sources should be carefully tracked and their provenance recorded through the indicator framework process. Data provenance refers to the described pathway that data for each selected indicator takes to become meaning as part of indicator evaluation. This pathway begins with justification for why a particular dataset is chosen to data management in a retrievable form linked to reporting on indicator condition.

This provenance pathway continues seamlessly with data analysis and reporting, which can be organized using the scientific workflow technique (Appendix E). Scientific workflows offer both a theoretical as well as a practical way for building a comprehensive environment for data management, analysis, and decision support. Scientific workflows combine scientific data and process workflows, and provide a graphical interface to manage the pipeline of steps of a scientific problem (Ludäscher et al 2009). One can think of scientific workflows as similar to a flowchart, where the various nodes represent computational tasks and the lines connecting each step are the informational inputs and outputs for each step. Each step can either be automated, such as an analytical task, or semi-automated, where external input and responses are required to complete the steps.

Distance to Target

Comparing indicator-parameter values to a reference or target condition is a critical step in the Framework. It is where sustainability meaning is attached to the data. There are a variety of ways to measure and normalize measurement of parameter conditions to target or reference conditions (see Appendix A for more detail).

In the Framework, normalization is carried out as each indicator is evaluated compared to a pair of reference or standard values (axiological normalization). Typically, there is a reference for “poor condition” (score = 0) and “good condition” (score = 100). When this is done for each indicator and each time point, the result is a “distance to target” value that can be on a 0-100 (or similar) scale. An important benefit of comparing indicator condition to targets is that scores can be combined across very different indicators (e.g., water temperature and fish tissue mercury concentrations), whereas otherwise this would not be possible. Because all indicator conditions are quantitatively compared to a target, they will all be normalized to the same scale — distance to target. Once the normalization takes place, the new values, ranging from 0 to 100, mean the same thing and can therefore be compared, or aggregated. Because environmental and socio-economic processes and conditions rarely respond to influences in a linear fashion, evaluating indicators relative to reference conditions must also take into account these non-linear responses. For example, evaluation of water temperature should follow a non-linear function because biological processes may respond non-linearly to changes in temperature (figure 2).

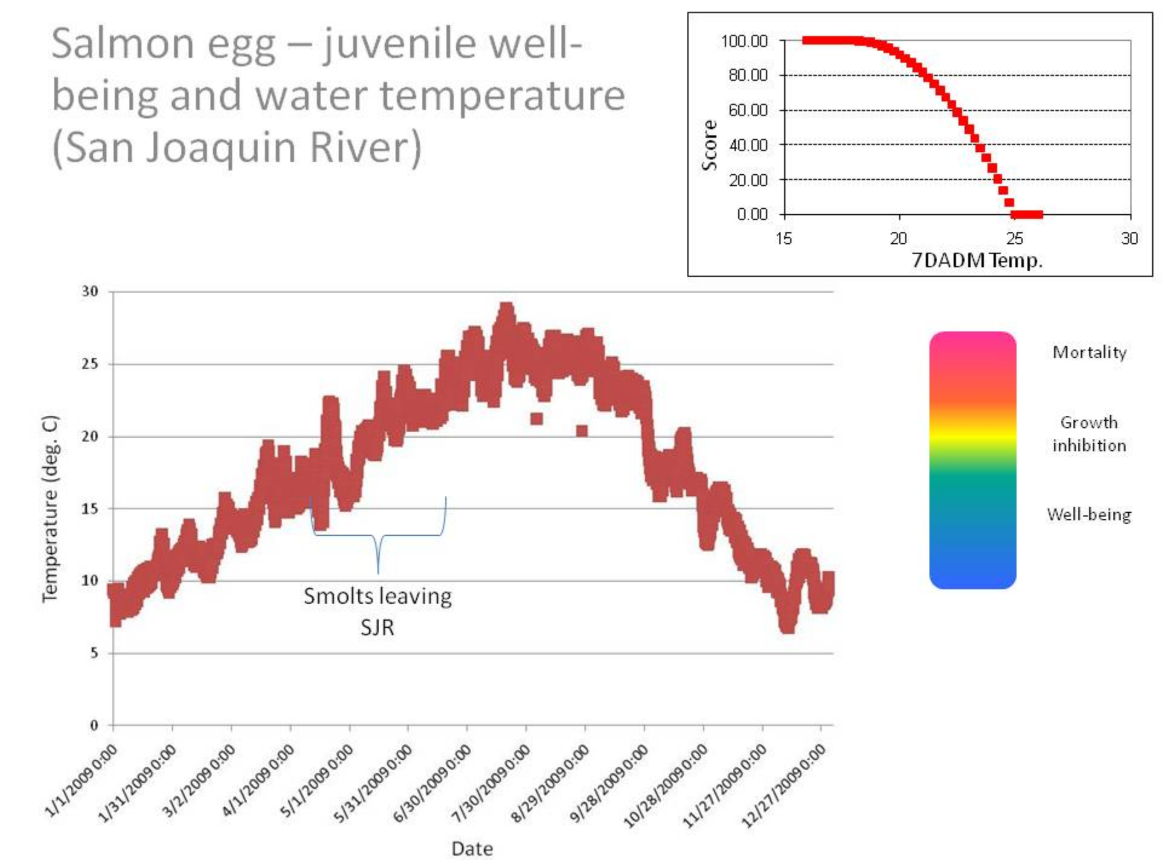

Figure 2. Comparison of salmonid young well-being to San Joaquin River water temperature. Inset graph: relationship between temperature and score for water temperature, based upon temperature sensitivity of salmonid young.

Trends Analysis

Changes in ecosystem characteristics over time are an important type of analysis and one of the most valuable types of information conveyed with indicators. Somewhat counter-intuitively, they are also rarely conducted using appropriate statistical techniques. Analysis of trend in time series data is necessary to determine if conditions in a sub-watershed are improving or deteriorating. One of the most common techniques for determining trend is linear regression. However, linear regression requires certain data characteristics, such as normal distribution of values, which are not easy to assess in small data sets. Distribution-free trend analysis is ideal due to the unknown nature of the data, so non-parametric tests are preferred. Of the various commonly used options, the Mann-Kendall rank correlation trend test is the strongest (Berryman et al. 1988). It is appropriate for data that are not normally-distributed, tolerates missing values, and is relatively unaffected by extreme values or skewed data. Related to the Mann-Kendall test, the Seasonal-Kendall test can be used to determine whether or not significant changes have occurred over time, while taking into account variation due to seasonal effects (Hirsch *et al*., 1982; Hirsch and Slack 1984; Esterby 1996).

Variance and Confidence

The degree of certainty in the indicator evaluation results depends on two conceptual questions: whether good indicators were chosen and how well the data presented for each indicator accurately reflect the real status or trend in the metric(s). The first of these questions pertains to the indicators themselves and how well they address the objectives or attributes they are meant to represent. Certainty about the indicators depends on four main factors: Importance, understanding, rigor, and feasibility. The second question pertains to statistical confidence in the data presented for each indicator. The available data may contain a variety of sources of uncertainty including: measurement error, uncertain or inappropriate use of the sampling frame, sampling error, and process error. Any of the above sources of uncertainty affects confidence in the estimates of status and reduces the ability to detect trends over time. For some indicators quantification of different sources of uncertainty in the data may be possible, but in many cases there are limitations to providing a quantitative description of the likely sources of error and associated magnitude. Reporting confidence, certainty, and/or variance is important to building trust for the indicators framework.

Step 5 Report Card

The Framework report card is the formalized reporting mechanism for indicator condition, trend in condition, and confidence in the findings. There are a variety of criteria for performance of an indicator report card. It should be understandable to the audience who is intended to benefit from indicator evaluation; it should be accurate and transparent; and it should aggregate information to a degree that does not mask especially poor or good conditions in the study area.

Goals	Measurable Objective	Condition	Trend	Confidence
Water quality and supply for natural and human communities	Water quality for aquatic health	50	↔	Medium-high
	Maintain natural stream flows	55	n/a	Medium
Protect and restore native animals and plants	Native birds	100	↔	Medium
	Native invertebrates	46	↔	High
	Native fish	49	↔	High
	Agricultural/urban development	90	n/a	Medium
Protect and enhance habitats, ecosystems, and watersheds	Protect aquatic connections	77	n/a	Medium-high
	Protect landscape connections	33	n/a	High
	Maintain natural production and nutrient cycles	82	↓	Medium
Maintain and restore natural disturbance	Restore natural fire regimes	9	↔	Medium
	Encourage natural flooding, while protecting people	50	n/a	Low
Improve social and economic conditions & benefits from healthy watersheds	Enhance wildlife-friendly agriculture	83	↑	Medium-high
	Improve community economic status	51	↓	High

Figure 3 Sample report card, Feather River Basin (Source: Shilling et al., 2010)

One possible strategy is to develop a very detailed reporting system in report form, or online, with resolution at a subunit scale and values provided for every metric and indicator (example: http://ice.ucdavis.edu/waf). A summary report card could then also be provided that measures progress toward meeting objectives and shows summary trend and confidence information (e.g., figure 3).

Effective online reporting of the Framework requires a model for the corresponding web framework (figure 4). In this model, information is sorted in two main ways in reporting – geographic and by indicator. These are likely to be common ways that people search for information, but there may be other mechanisms. Another possibility is to develop a real-time, online indicator system that takes parameter values available online and uses the steps here to convert data streams into measures of sustainability in an automated way.

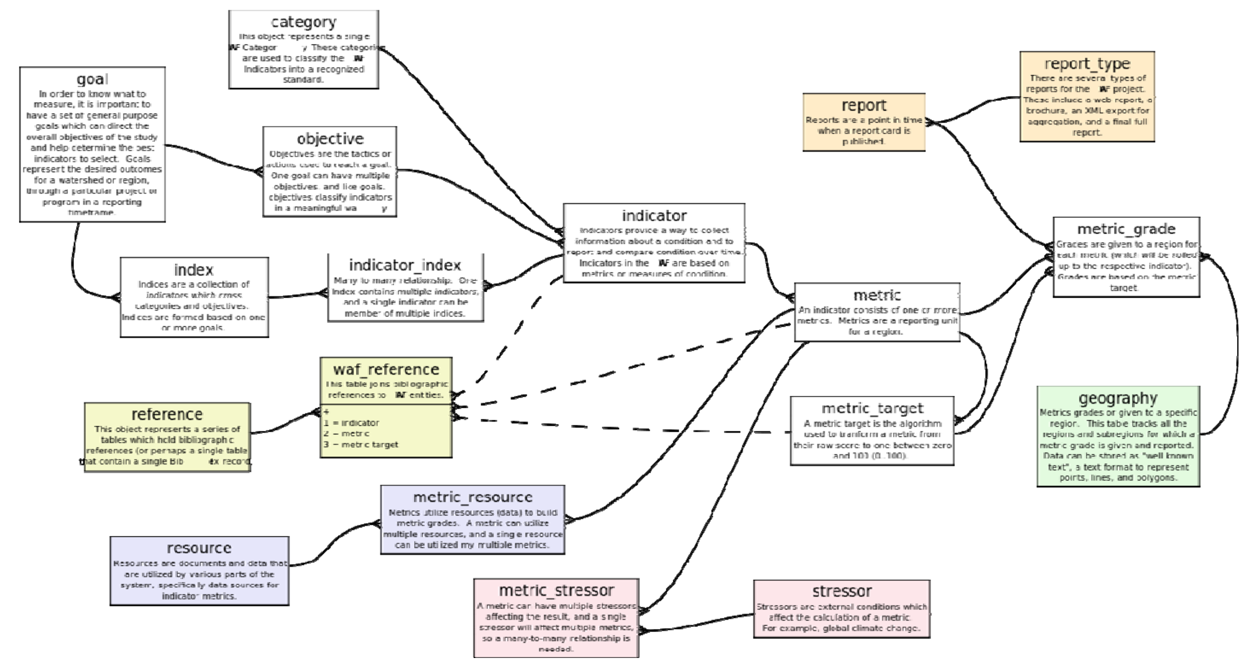

Figure 4. Data model for web-version of a sustainability report card.

Step 6 Knowledge Building and System Performance

Evaluating indicator condition can provide several types of information. One is improved knowledge about the functioning of usually-complex systems by the public, decision-makers, and scientists alike. In order to carry out this function, the Framework should include indicators that both measure progress toward meeting objectives and represent many aspects of complex systems. Another function is measuring performance of programs and management actions intended to be sustainable. This last function is embedded in sustainability objective 7, which relates to the deliberate use of scientific information in decision-making.

Step 7 Policy and Behavioral Response

Achieving sustainability requires measuring social, economic, and environmental condition and developing actions and policies to respond to degraded conditions and to promote improving conditions. Developing appropriate responses requires accurate condition assessments and linkages between influences and condition change. Developing responsive behaviors and policies is the hard work of the proposed Framework. It often requires negotiation among competing interests, who may question the information provided by the Framework. To help with this process, the report card should convey the relative confidence, or certainty, in the condition assessment. Condition and trends assessment combined with confidence and linkage models can provide the basis for sustainable policy and behavioral responses.

II.B Intersection of Indicators with Natural and Management Systems

Indicators and IRWM Regions and Planning

Embodying a clear and consistent stakeholder driven vision, a step by step methodology, a suite of indicator reporting methods, a set of consistent terminologies, and important references, the proposed California Water Sustainability Indicators Framework is envisioned as a transparent and documented framework for evaluating the sustainability of California's water resources and systems. It is conceived as a tool for monitoring progress towards the state's water resources sustainability through meeting the objectives of the California Water Plan through a set of relevant, quantifiable indicators. One of the significant anticipated utility of the Framework is that it will provide a toolbox, useful templates, and a set of illustrative examples for IRWM regions to conduct water sustainability indicators analysis for local and regional water management. By utilizing this Framework, local and regional water agencies comprising the IRWM regions may be able to improve their water resources sustainability through an evaluation of condition and trends of relevant indicators reflective of their particular needs. The process will also help identify issues and data gaps to inform future data monitoring needs on a local and regional scale to enable better quantification of water sustainability indicators in the future. Similar to that for the state as a whole, the indicator analysis on a local and regional scale by the IRWM regions is also expected to highlight policy needs for ensuring the local and regional water resources sustainability.

Indicators and Ecosystem Services

Ecosystem services need to be considered in developing the California Water Sustainability Indicators Framework (see Appendix F for a detailed discussion on ecosystem services). One conceptual model for ecosystem services connects ecosystem processes (e.g., nutrient cycling) and features (riparian forest) to the provision of ecosystem services (e.g., pollination by native pollinators), which in turn provide benefits to humans (e.g., increased agricultural production).

Each of these steps can have associated indicators (figure 5), which not only help describe and quantify the ecosystem services, but can serve to link this concept to the Framework.

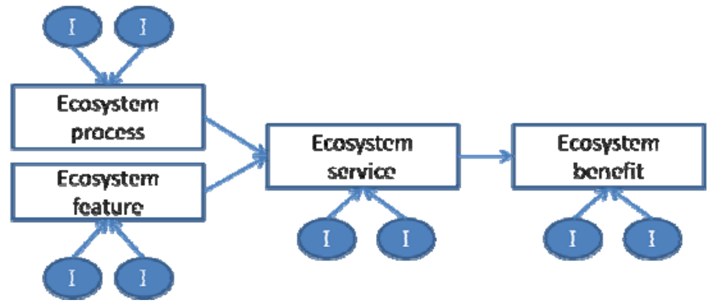

Figure 5 Indicators ("I" in circles) in the ecosystem services model.

A companion effort is underway by the Water Plan work team to quantify ecosystem services and the associated benefits. The Framework work team will work closely with the Water Plan ecosystem services work team to ensure consistency among the efforts.

Indicators and Ecological and Water Footprints

An ecological footprint is a measure of the impact humans have on the earth. In the simplest terms, it is a measure of resource consumption and waste production compared with the planet's natural ability to generate new resources and absorb waste. Calculations are based on land area required to produce and assimilate these resources and wastes within six land use types: cropland, grazing land, fishing ground, forest land, built-up land, and the uptake land to accommodate the carbon footprint (a measure of carbon dioxide release and natural absorption) (Global Footprint Network 2010).

The ecological footprint is a useful indicator for determining long term sustainability because it incorporates many facets of consumption and renewal in a manner that is measurable and useful in management (Wackernagel and Yount 1998).

The relevance of the ecological footprint with regards to the California Water Sustainability Indicators Framework is evident in the water footprint, which is derived conceptually and is related to the ecological footprint idea. The water footprint is the relationship between direct or indirect uses of water used to produce goods and services consumed by humanity. Agricultural production accounts for most of global water use, but drinking, manufacturing, cooking, recreation, washing, cleaning, landscaping, cooling, and processing all contribute to water use (Hoestra et al. 2011). In addition to these direct water uses, indirect uses such as water impacted by pollutants, chemical or temperature, contribute to the water footprint (see Appendix G for more discussion).

A companion effort "California Footprint Sustainability Indicators for Decision Support" led by the USEPA is underway. The two major components of this effort are the development of ecological and water footprints. Global Footprint Network will lead the ecological footprint analysis, while DWR and UC Davis, in partnership with USEPA, will lead the development of the water footprint analysis. The Framework work team will work closely with the Global Footprint Network work team to ensure consistency among the two efforts.

Indicators and Water Plan Scenarios

An important component of the Water Plan is development of potential scenarios for populations, land-use patterns, irrigation, water conservation, precipitation, and summer temperatures. In combination, these parameters can be used to model water management under possible future conditions. In an attempt to describe boundary states for possible future conditions, the Water Plan currently solves for a combination of conditions for each parameter for three plausible growth scenarios (current trend, slow and strategic growth, and expansive growth) and 12 climate change scenarios for conditions in 2050 that are designed to capture a range of future uncertainties (DWR, 2009).

The primary parameters in scenario modeling can be treated as drivers in the water cycle that have measurable responses: environmental, agricultural, drinking, commercial/industrial, and all water. Indicators for both the drivers and responses can be and are included in the Framework. This allows potential future conditions and management responses to be modeled and assessed in the context of sustainability of water resources and systems.

Drivers	Responses
Irrigated Crops	Environmental Water
Summer Temperatures	Agricultural Water
Population	Drinking Water
Land-Use	Commercial/Industrial Water
Water Conservation	All Water
Precipitation	

II.C Where We Were and Where We Are Going

Where We Were:

In early 2010, California Water Plan's work team initiated the development of the envisioned California Water Sustainability Indicators Framework. Through a series of internal discussions over a period of several months in 2010, the work team developed a project charter for the Framework. Further discussions were held with the Sustainable Water Resources Roundtable, the Bay Institute, the Delta Stewardship Council, and the Strategic Growth Council during 2010 and 2011. Based on these discussions, the project charter was revised accordingly.

As part of Water Plan's outreach process, the project vision, objective, and deliverables were introduced to the State Agency Steering Committee, the Public Advisory Committee, and the Tribal Advisory Committee. Based on their feedback, the project charter was further revised.

In early 2011, DWR engaged UC Davis to provide technical support to the project to assist in the development of the Framework, drawing upon concepts used in indicator system development by UC Davis in three regions of California. During the same time, USEPA Region 9 initiated and finalized discussions with DWR to collaborate in the project through financial and advisory support.

Where we are going:

The draft Framework is in development. It is currently undergoing review by the Water Plan Sustainability Indicators Workgroup with interagency participation.

In late August 2011, the Framework will be introduced to both the State Agency Steering Committee and the Public Advisory Committee to seek their feedback and comments. In a separate workshop in early August, the Framework will be presented to the Tribal Advisory Committee. During the same timeframe, the Framework will also be presented to the Statewide Water Analysis Network in an upcoming workshop to vet the technical approaches and methodologies proposed in the Framework.

The Sustainable Water Resources Roundtable is coordinating with DWR to have the Framework launched as a major topic in its Fall 2011 workshop scheduled for late October 2011.

Finally, the Framework will be introduced in several Water Plan Regional Forums planned in 2011 and 2012 to incorporate the perspectives of the regional stakeholders. This will be an ongoing process and will continue even after the Framework has been nominally finalized.

The Framework is anticipated to take a final shape by the end of 2011, with the recognition that it may continue to evolve and get refined in the future as it is applied to conduct quantitative analysis on selected Pilot study regions.

Starting in end of 2011 and through 2012, the Framework will be implemented as a Pilot study in at least one region of California in order to assess its utility. Implementation will involve: 1) selection of a Pilot study region, 2) interaction with regional stakeholders regarding regional objectives and data sources, 3) data collection and analysis, and 4) evaluation of water sustainability indicators for the Pilot study region. The water footprint work described in the following section, an integral component of the Framework, will also be a part of the Pilot study.

Coordination with Related Efforts

<u>USEPA:</u> DWR and UC Davis are closely collaborating with USEPA's California Footprint Sustainability Indicators for Decision Support project. The two major components of the project are the development of ecological and water footprints. USEPA has engaged Global Footprint Network to conduct the ecological footprint analysis at the State of California level to compare

the population’s use of natural resources with the ecosystem’s ability to provide those resources. In partnership with USEPA and as part of the Framework development, DWR and UC Davis will lead the development of a water footprint analysis to fill the gap in the ecological footprint methodology. This will involve use of specific sustainability indicators, incorporated into a footprint assessment in a specific region of California.

Strategic Growth Council: DWR and UC Davis are working with SGC in order to coordinate the indicator analysis carried out in SGC’s regional progress reports.

Regional Agencies: UC Davis is working with several local and regional partners and companion efforts to encourage more coordination among similar efforts in California. For example, the San Diego Regional Water Quality Control Board is developing a water quality report card for San Diego Creek and is collaborating with UC Davis so that the methods are the same as in the California Water Sustainability Indicators Framework. The Sonoma County Water Agency is similarly interested in partnering with DWR and UC Davis on implementation of the Framework in watersheds and counties of the North San Francisco Bay. UC Davis is working with the Sacramento Regional County Sanitation District on developing a water quality report card for the Lower Sacramento River that will also be consistent with the Framework.

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Appendix A Glossary of Terms

This appendix provides a list of terms useful in communicating effectively and ensuring consistency among similar sustainability indicator systems [1] The terms and definitions are primarily based upon the work of three regional California Watershed Assessment Framework (CWAF) projects conducted between 2008 and 2011[2]. The CWAF was built to meet watershed monitoring needs and performance measures identified in the California Watershed Management Strategic Action Plan. The terms and definitions originated from a combination of reports and background documents from state, federal, and global efforts towards developing social and ecological condition reporting frameworks for monitoring condition and performance.

Sustainability Indicators Framework

The Sustainability Indicators Framework (SIF) is in an evaluation framework developed for use at the scale of natural or jurisdictional. The concept and use of the SIF is partially based upon the CWAF structure and process, which was in turn based upon an approach developed by the USEPA's Science Advisory Board and has been adapted

The framework provides a scientifically defensible approach for aggregating and assessing a variety of environmental, economic and social information. The framework can be used to assist in linking the condition of a study area's natural and social structures into a broad framework consisting of the sum total of the physical, chemical, social and biological components of the study area and how they interact and change over time. The SIF includes evaluation of economic and social conditions and is a way of integrating

Weak sustainability : "According to the weak approach of sustainable development, natural capital is a component of the total capital composed by all the productive goods, so-called productive capital, human capital and the stock of knowledge and know-how of the people, so-called social capital, and the resources and natural goods, renewable or not, so-called natural capital. These different types of capital are supposedly measurable and equivalent. The annuities due to the use of the natural capital by the present generation can be reinvested in the form of a reproducible economic capital, to be transmitted to the future generations. […] In these conditions, the sustainable development of an economic sector is not limited by an ecological constraint."

Strong sustainability : "The second variant of sustainable development is the strong approach, which claims the irreducible character of the natural capital. It means that the sustainable development should comply with the ecological constraints due to the preservation of the quantity and the quality of the natural capital, i.e. nature."

[1] http://www.water.ca.gov/watersheds/framework.cfm

[2] Developed by Fraser Shilling (UC Davis) based on the index/indicator literature and feedback from Jeff Sharp (Napa County) and Mike Antos (Los Angeles San Gabriel Rivers Watershed Council).

consideration of environment, economics, and social conditions at natural or jurisdictional scales/extents. The SIF acknowledges that humans and their activities are integral parts of ecosystems and that most human endeavors depend upon healthy natural systems.

Systems

Indicators are usually chosen to represent parts of complex systems. A system, as the term is used here, is a set of interacting parts, where both the components and the relationships among them is part of the system. For example, an ecosystem is composed of interacting organisms and natural processes, an economic system is composed of interacting people and organizations/institutions. It is usually important when using this term to define the boundary conditions for the particular application of the term. For example, the idea of a social system is very abstract, but the concept of social systems in Fresno County provides more context for the term.

Social and Ecological Themes, Domains or Categories

A category is a class of similar concepts, ideas, or things within in an organized and rule-based system to discriminate among classes where the discrimination is based on apparent differences among the categorized objects. Themes and domains are types of category and are terms of art referring to large parts of natural or social systems (e.g., landscape condition). Categories, themes and domains are one way to organize information in an overall condition index, like the SIF, where the categories and sub-categories are used to classify related indicators (figure 1). The 8 essential attributes identified in the CWAF valuation projects is a means to categorize various attributes that describe a watershed and are described below.

Figure 1 Indicators nested within sub-domains, in turn nested within domains

Landscape Condition The extent, composition, and pattern or structure of (non-human) habitats in a landscape.
Biotic Condition The condition or viability of communities, populations, and individual biota (i.e., at the scale of individual habitat types).
Ecological Processes Metabolic function of ecosystems - energy flow, element cycling, and the production, consumption, and decomposition of organic matter at the ecosystem or landscape level.
Social Condition The examination of the organization and development of human social life within the watershed, including measurements of community and social patterns, and behavior of individuals and groups.

Economic Condition Measures of the production, distribution, and consumption of goods and services within a watershed, including the valuation and of non-market resources that provide individual and community utility.
Chemical and Physical Characteristics Physical parameters and concentrations of chemical substances present in the environment/watershed (water, air, soil, sediment).
Hydrology/Geomorphology Characteristics that reflect the dynamic interplay of surface and groundwater flows and the land forms within the watershed.
Natural Disturbance The historical and/or contemporary function of discrete and usually recurrent disturbances, which may be physical, chemical, or biological in nature, that shape watershed ecosystems.

Goals & Objectives

"***Goals and Objectives***. *Ideally, environmental management programs begin with a process to develop goals and objectives that articulate the desired ecosystem conditions that will result from the program(s)*." (USEPA SAB Report)

<ins>Goals</ins> describe desired outcomes for a watershed or other natural or social system, through a particular project or program in a stated timeframe. In the case of the SIF, goals are described in the CWP, relating to the desired outcomes for the study area in some stated timeframe.

<ins>Objectives</ins> are the tactics to the goals' strategies. They describe actions that can be taken to implement or reach goals and are often nested within goals (figure 2). Objectives for systems can be defined as actions that help reach desired outcomes for particular aspects of the system's condition.

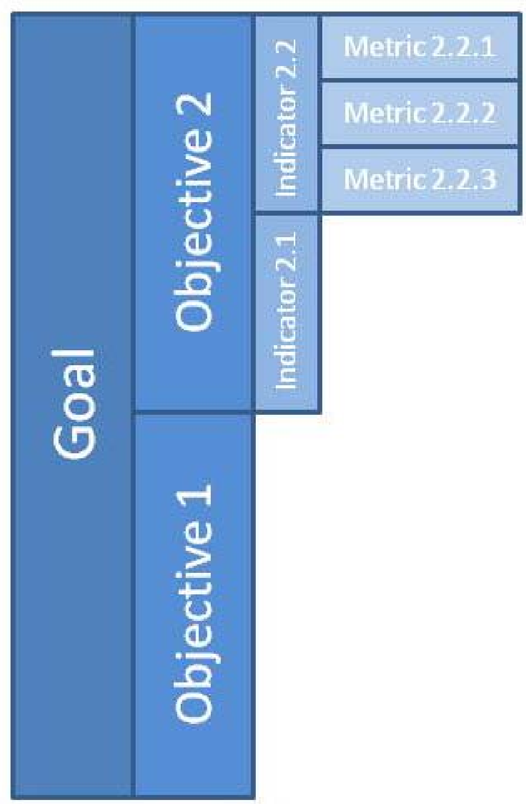


Figure 2 Nested metrics, indicators, and objectives within goals

Index

Sometimes organizations want to develop a comprehensive understanding of environmental or social health and express that as a single score, which is a composite of several or many indicators. This composite is usually called an index. In terms of the SIF, you could imagine scores for indicators within a domain called "water quality" being composited into an overall attribute score for water quality. In this case, the domain is functioning as an index. The SIF is also an index, composed of the component indicators nested within goals and/or objectives, though a single index score for the SIF may be only generally meaningful.

Indicators

*“**Ecological Indicators** (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems. Multiple indicators may be associated with each subcategory in the EEA [essential ecological attribute] hierarchy.*” (USEPA SAB Report)

<u>Indicators</u> (the backbone of the SIF process) provide a way to collect information about a condition and to report and compare condition over time. Indicators in the SIF are organized within goals, objectives (figure 2), and domains (figure 1) and are based on metrics or measures of condition, though sometimes indicators and metrics are the same thing.

Metrics/measures

“***Measures.*** *The measures are the specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators*.” (USEPA SAB Report)
<u>Metrics/Measures</u> are the building blocks of indicators and thus the foundation of a condition assessment system. Examples of metrics and measures include dissolved oxygen concentration, proportion of successful nests (i.e., produce young) per season for a particular riparian bird species, and fire return interval for a particular plant community within a study area. Each of these measures might fit into an indicator composed of one or more metrics (e.g., “fire dynamics”) that in turn is categorized into a system domain (e.g., natural disturbance) or goal.

Goal	Objectives	Indicators
A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities	1) Maintain water quality for healthy aquatic systems	i. Periphyton Cover and Biomass
		ii. Surface Water Temperature
		iii. Mercury in Fish Tissue
	2) Maintain and restore natural stream flows for aquatic and riparian communities	i. Flow Patterns and Alteration
B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities	1) Protect and enhance native bird populations	i. Bird Species Diversity
	2) Protect and enhance native aquatic invertebrate communities	i. Proportion of Watershed in Agricultural/urban Development
	3) Protect and enhance native fish populations	ii. Benthic Macroinvertebrates Community Structure
		iii. Fish Community Diversity
C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions	1) Protect and enhance aquatic habitat connectivity	i. Aquatic Habitat Barriers
	2) Protect and enhance terrestrial (native upland) habitat connectivity	ii. Terrestrial Habitat Fragmentation
	3) Protect and maintain natural variability and rates of primary production and nutrient cycling	i. Carbon Stock and Sequestration
		ii. Nitrogen Load/Cycling
D. Maintain and restore natural disturbance processes that balance benefits for natural and human communities	1) Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities	i. Fire Frequency
	2) Reduce flood risk to human communities and encourage natural flood processes that support native communities	i. Flooding and Floodplain Access
E. Maintain and improve the social and economic conditions, including benefits from healthy watersheds	1) Protect and enhance wildlife friendly agricultural practices	i. Pesticide Application and Organic Agriculture
	2) Improve community economic status in balance with watershed condition	i. School Lunch Program Enrollment

Figure 3. Example use of objectives and indicators nested within goals in a report card format for the Feather River Basin (Shilling et al., 2010).

Variance and Confidence

The degree of certainty in the Report Card results depends on two conceptual questions: whether good indicators were chosen and how well the data presented for each indicator accurately reflect the real status or trend in the metric(s). The first of these questions pertains to the indicators themselves and how well they address the objectives or attributes they are meant to represent. Certainty about the indicators depends on four main factors: Importance, understanding, rigor, and feasibility.

»»Importance — the degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome,

»»Understanding — the degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s),

»»Rigor — the degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested or confounded by other information, and
»»Feasibility — the degree to which input data necessary to calculate the proposed performance measure can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.

The second question pertains to statistical confidence in the data presented for each indicator. The available data may contain a variety of sources of uncertainty including: measurement error, uncertain or inappropriate use of the sampling frame, sampling error, and process error. »»Measurement error. Random or systematic errors introduced during the measurement process, sample handling, recording, sample preparation, sample analysis, data reduction, transmission and storage (USEPA 2006; Thompson 2002)
»»Uncertain/inappropriate interpretation of sampling frame. Errors in inference resulting from opportunistically mining the available data without knowledge of the sampling frame1. For example, macro-invertebrate data may have been collected by several different studies with different objectives and target populations (e.g. they could have focused on different stream orders). Without this knowledge, we must make assumptions about the probability of selecting each site and the appropriate weighting of the observation.
»»Sampling error. The error resulting from only examining a portion of the total population (Cochran 1977; Lohr 1999; Thompson 2002), if a census of the population is taken (e.g., school lunch enrolment) then there is no sampling error.
»»Process error. Actual variability between spatial or temporal units in the population. This source of variability exists even if a census is taken with no measurement error. This is often referred to as natural variability.

Any of the above sources of uncertainty affects confidence in the estimates of status and reduces the ability to detect trends over time. For some indicators quantification of different sources of uncertainty in the data may be possible, but in many cases there are limitations to providing a qualitative description of the likely sources of error and associated magnitude. Reporting confidence, certainty, and/or variance is important to building trust for the indicators framework.

Distance to Target

Comparing indicator-parameter values to a reference or target condition is a critical step in the Framework. It is where sustainability meaning is attached to the data. There are a variety of ways to measure and normalize measurement of parameter conditions to target or reference conditions.

The table below summarizes the main methods, their advantages and disadvantages.

Method	
Advantages	Disadvantages
Empirical normalization	

<table>
<tr><td colspan="2">Min max method gives the 0 value (Min) to the most unfavorable observed value and 1 or 10 (Max) to the best recorded value. All intermediary values are calculated based on the formula: Y = X – Min/(Max – Min).</td></tr>
<tr><td>Simple and efficient to compare alternatives with an initial state</td><td>Variability of Min and Max values that depend on observed values, new observation outside the previous limits will lead to new normalization. Extreme values/or outliers could distort the transformed indicator</td></tr>
<tr><td colspan="2">Axiological normalization
Close to the empirical approach with min and max limits. The limits are not statistically identified, being chosen based on the undesirable situation, which receives the “0” value, and on the ideal situation, which can or cannot correspond to a strategic objective and which receives the value “1”.
Alternatives to min and max here are :
• distance to a reference method that takes the ratios of the indicator to a value of mean reference for this indicator: $Y=X/X_{expected}$
• Indicators above or below the mean : this transformation considers the indicators which are above and below an arbitrarily defined threshold, p, around the mean $X_{expected}$:
$$Y = \begin{cases} 1 \ if \dfrac{X}{X_{expected}} > (1+p) \\ 0 \ if \ (1-p) < \dfrac{X}{X_{expected}} < (1+p) \\ -1 \ if \dfrac{X}{X_{expected}} < (1-p) \end{cases}$$</td></tr>
<tr><td>Simple and efficient to compare alternatives.
Reduced impact of extreme values</td><td>Might be less realistic than the empirical approach because limits depend on objectives, not on observations</td></tr>
<tr><td colspan="2">Mathematical normalization
Transformation of data by means of a mathematic function in order for the values to range between an upper and a lower limit</td></tr>
<tr><td></td><td>Lack of transparency for the user and possible change of initial distribution of values</td></tr>
<tr><td colspan="2">Statistical normalization
All values are expressed in standard deviation, so that the variables average is equal to zero</td></tr>
<tr><td>Does not depend on min and max values determined by strategic objectives or statistics</td><td>Does not depend on min and max values determined by strategic objectives or statistics</td></tr>
</table>

This measurement of distance to a target or reference condition is sometimes called the “ideal point” method (Malczewski, 1999). The ideal point method was first introduced in the late 1950s and expanded by Milan Zeleny in the 1970s (Pomerol and Barba-Romero 2000). Zeleny (1982) described the measurement of closeness with: $d_i = f_i^* - f_i(x_{ji})$ where d_i is the distance of attribute state x_{ji} to the ideal value f_i^*, i indicates the attribute and j indicates the objective.

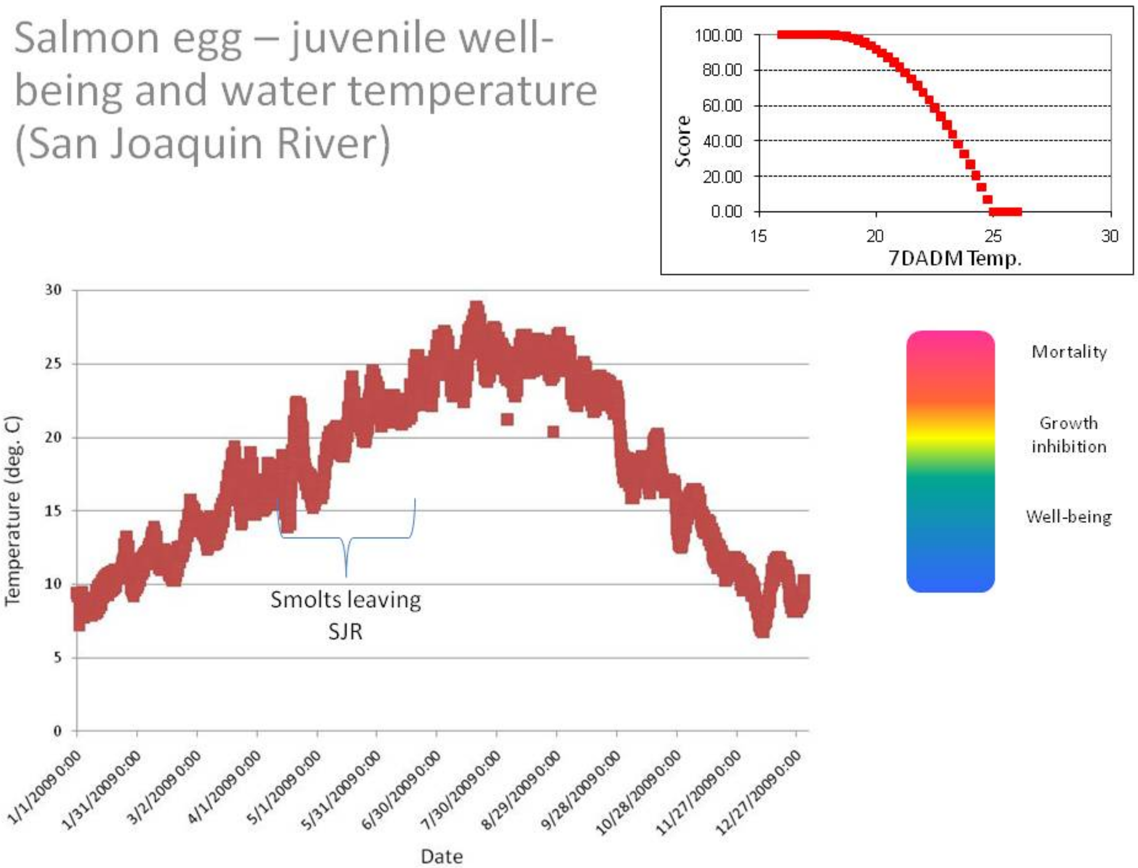


Figure 2. Comparison of salmonid young well-being to San Joaquin River water temperature. Inset graph: relationship between temperature and score for water temperature, based upon temperature sensitivity of salmonid young.

Appendix B Indicator Selection Criteria

Availability of high-quality data

One of the main obstacles many face when selecting indicators is the lack of available data. Frequently the data for an indicator that may be important are not available. Alternatively, the data might only be available for random points in time or for limited geographical areas. The data might have been collected for one purpose in a particular way that served the original purpose, but for your purposes, it may be inadequate. If new data are needed, the feasibility of collecting them might be limited by the amount of effort required to accurately make the measurement (e.g., actual salmon escapement). Alternate indicators may be considered that have significantly lower cost (e.g., remote-sensing based habitat assessment). For certain indicators, it may be very cost-effective to collect the required metrics (e.g., habitat assessment for a species of concern), but the indicator may not represent the process of concern compared to more expensive indicators (e.g., actual population trends in the species of concern). Data collection and analysis costs (further described as a separate criterion below) have to be evaluated in relation to the potential cost and societal implications of a proposed action or inaction, i.e., the greater the expected tradeoffs between societal goals, the greater the need for certainty in the environmental outcome. When choosing indicators, it is essential to carefully consider the current availability of data for the indicator, as well as how much data will be available in the future from our own collection and from the efforts of others. The availability of metadata is one criterion for selection of particular data for corresponding indicators. Finally, indicators will be useful and useable in the long-run if there is a process for updating the corresponding database, metadata, and data collection & QA/QC procedures.

Long-term data affordability

One factor to consider in evaluating indicators is the costs associated with collecting and analyzing data. One consideration in evaluation the costs and benefits is the usefulness of the information for evaluation of management and ecosystem condition. Indicators that are cost-effective, while accurately representing ecosystem characteristics are preferable. The primary guide is that the amount of data required to adequately report on condition and change in condition can be and are being collected with the resources available. The data should also be collected in a standardized way for which there are QA/QC procedures described. For critical indicators (those reflecting important system conditions for which there is no viable alternative), more resources may need to be made available if they are currently inadequate.

System representation

Another factor to consider in indicator selection is how well the indicator reflects the issue for which it was selected. Frequently, certain indicators are widely recognized to be a useful measure for an issue. Selecting these indicators is usually a ‘safe bet’. For example, percent riparian canopy cover is considered a good indicator of riparian conditions because it has been extensively studied and shown to have a good relationship with stream temperature and the detection of changes can be made easily. Selecting indicators that have been carefully evaluated for their scientific validity means they usually have wider acceptance than those that haven't been studied very much, and they are more likely to allow you to make confident inferences about system condition. Indicators that are representative of large aspects of system condition and trends are preferable for those that have narrower utility, all else being equal. Sometimes the condition is itself an important ecosystem driver. For example, surface water temperature is an important ecological variable for understanding the condition of aquatic ecosystems. It is also the target of management actions to benefit these ecosystems, which is another criterion described below. Indicators that can provide important information at both broad and fine spatial scales are likely to be more useful as they can help inform both strategic and site-specific decisions.

Sensitivity to change over time

The ability to report on trends over time is a key function of an indicator. The availability of a data set collected over a period of many years is ideal. Indicators that respond relatively quickly to management intervention and can effectively be used to measure change over time may be preferable to those that require data over long periods of time to observe changes due to management actions. This is especially useful in reference to short-term grants and contracts, or short-term program evaluation, which require performance measures to demonstrate the success or failure of the project. If possible, select indicators whose range of natural variation can be quantified and that permit change detection over short periods of time (2-3 years). At the same time, recognize that many of the processes that we try to improve with restoration programs take decades or longer to change or recover (e.g., salmon population recovery). Indicators for these projects and programs should be stable over these longer timeframes (i.e., decades).

Independence of indicators from one another

Independence refers to how related indicators are to each other. Road density and %impervious surface are related indicators because roads are often impervious. Indicators that are relatively independent are preferable (e.g., rate of ground water use for irrigation and migration barriers), while recognizing that some critical indicators are related and somewhat dependent on each other (e.g., surface water temperature, flow, stream shading, hydraulic connectivity to groundwater, salmon rearing habitat suitability). The concern about independence is important for designing efficient indicator systems, but is secondary to choosing easily-measured and representative indicators. You may choose related indicators, but you would be constrained in your attempts to use them together to explain condition of a system. For example, if (a) surface water temperature, (b) flow, (c) stream shading, (d) amount of groundwater withdrawal, and (e) salmon rearing habitat were indicators of success for a restoration program, then you could not report changes in these indicators without acknowledging that (a) depends on (b), (c), and (d); (e) depends on (a), (b), (c), and possible indirectly on (d) through (b); and (c) may depend on (b) and (d). If restoration of riparian shade (c) was a goal in order to benefit salmon rearing (e), then the inter-dependence of some of the other parameters would need to be acknowledged and potentially controlled-for in order to measure the true effect of increased riparian shade on salmon rearing.

Supports management decisions and actions

Measuring conditions in the environment and in communities can inform policy development and social/fiscal investments. Indicators should be informative in evaluating environmental/social/economic conditions, as well as the influences on these conditions. Another useful characteristics of indicators is that they can be used to evaluate the effects or effectiveness of management actions — be it a state or federal agency or the goals and objectives of a watershed council. Whatever the business of the organization is, indicators should provide information that can be used to assess the effectiveness of the work and efforts of the group. In the past, *activities* were seen as a measure of the effectiveness of an organization. The number of grants awarded, the number of pamphlets distributed, or similar "bean counting" has been used extensively to evaluate an organization's productivity. Environmental performance measures, on the other hand, look at the environmental and social *outcomes* of these activities to determine an organization's effectiveness. This is the reason it is so important to select indicators that are closely linked to management actions and decisions and that can be reported and understood in public arenas. The point of most indicators is to inform a wide audience about conditions in the environment and communities. Indicators should be science-based and easily understood by various kinds of decision-makers (e.g., scientists, public, elected officials). They should be equally presentable in summary form in newspapers and on web sites. Finally, indicators should be based upon reportable technical & scientific information and links easily made between summary presentations and the source data and knowledge.

Appendix C Indicator Systems from Around the Globe

Learning from Other Efforts in California and the US

The Water Sustainability Indicators Framework will not be developed in isolation. We intend to benefit from the lessons learned from other similar efforts described below.

Since 2002, the Sustainable Water Resources Roundtable has brought together State, federal, corporate, nonprofit, and academic sectors to advance understanding of the nation's water resources and to help develop tools for understanding and ensuring their sustainability (acwi.gov/swrr/index.html). SWRR has developed a five part framework with a set of 14 key sustainability indicators that can be useful for other entities developing their own indicators.

The Sacramento River Watershed Program beginning in 1996 developed the Sacramento River Watershed Management Plan that included a Roadmap and Watershed Health Indicators Program. The Roadmap provides an overview of the basin's six subregions and a picture of watershed health within the Sacramento River Basin. The Watershed Health Indicators Program uses the Watershed Assessment Framework to better understand some of the relationships between social, economic, and environmental conditions, and watershed management actions. The Watershed Health Indicators Program Report Card effort was launched in 2008, focusing on the Feather River Watershed for tracking watershed conditions and trends.

The Bay Institute Ecological Score Card was first produced in 2003 and then updated in 2005; another update is anticipated in 2013. In 2005 update, more than three dozen science-based indicators have been used to grade the condition of the Bay region. These indicators were combined into eight indexes. The score card system compares current conditions in the Bay and its watershed to: historical conditions, environmental and public health standards, and restoration targets.

State of the Great Lakes 2009, an undertaking by the U.S. EPA and Environment Canada, used Environmental Indicators for assessing status and trends of the Great Lakes Ecosystem (Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario). The status of ecosystem components was assessed in relation to desired conditions or ecosystem objectives. The effort assessed 62 ecosystem indicators categorized into 8 different groups.

2010 Environmental Performance Index (EPI) was prepared by the Center for International Earth Science Information Network (CIESIN) at Columbia University. The effort ranks 163 countries on 25 performance indicators, tracked across 10 policy categories covering both environmental public health and ecosystem vitality.

Framework name	Project URL	Complete report URL	Date	Institutional lead	Constituents
An Indicator Framework for Linking Historic Preservation and Community Economic Development		http://www.springerlink.com/content/j3t4186157728877/fulltext.pdf	Mar 29 2011	Arizona State University School of Community Resources & Development	
Sustainable Industries Performance Indicator Framework	http://www.ecoindustrial.ca/usgbc_toolkit/	http://www.ecoindustrial.ca/usgbc_toolkit/SustainableIndustryIndicatorsFinalReport23Mar05_protected.pdf	Mar 23, 2005	Industry Canada's Sustainable Technologies and Service Industries	
Framework for Measuring Sustainable Development in Catchment Systems	http://planet.uwc.ac.za	http://planet.uwc.ac.za/nisl/Gwen%27s%20Files/GeoCourse/Integrated%20Environmental%20Management/IEM/Peer%20Reviewed/Walmsley2002.pdf	2002	Mzuir Consultants, South Africa	
Transport Monitoring Indicator Framework	http://www.transport.govt.nz/ourwork/tmif/	http://www.transport.govt.nz/ourwork/TMIF/Documents/TMIFV2%20FINAL.pdf	2009	Ministry of Transport, New Zealand	
Food Security Indicators and Framework for Use	www.fantaproject.org	http://www.fantaproject.org/downloads/pdfs/fsindct	Jan 1999	US Aid	

in the Monitoring and Evaluation of Food Aid Programs		r.PDF			
Framework to evaluate ecological and social outcomes of collaborative management: lessons from implementation with a northern Arizona collaborative group.		http://www.springerlink.com/content/2u4lk31q6558uu28/fulltext.pdf		School of Sustainability, Arizona State University	
JSEM: A Framework for Identifying and Evaluating Indicators		http://www.springerlink.com/content/p36j1x36832834pl/fulltext.pdf	Dec 1998	Dynamic Corp Environmental Servces, US EPA, Corvallis OR	
A quantitative indicator framework for stand level evaluation and monitoring of environmentally sustainable forest management		http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6W87-50SJMGB-1-6&_cdi=6647&_user=4421&_pii=S1470160X1000124X&_origin=gateway&_coverDate=03%2F31%2F2011&_sk=999889997&view=c&wchp=dGLbVtz-zSkWA&md5=7bc9184b665e83a1c156a9a97593a610&ie=/sdarticle.pdf	13 Nov 2009	Ghent University (lead author)	

Biodiversity Indicators Partnership	http://www.bipindicators.net/	http://www.bipindicators.net/LinkClick.aspx?fileticket=NYhSvmOUgps%3d&tabid=155	2010	BIP	
Puget Sound Partnership	http://www.psp.wa.gov/	http://www.psp.wa.gov/downloads/SP2009/IndicatorSummaryReport(Final)120108.doc http://www.psp.wa.gov/downloads/SP2009/IndicatorEvaluationSpreadsheet091308.xls	2008	PSP	
Sustainable Water Resources Roundtable	http://acwi.gov/index.html	http://acwi.gov/acwi2008/slide.lib/SWRR-Indicators-Feb05Draft-Part1and2combined_new.pdf	2008	Advisory Committee on Water Information	
Coastal Institute	http://www.ci.uri.edu/	http://www.ci.uri.edu/Projects/PNB/Chafee-HUD/Indicators_Final.pdf	2003	CI – Narragansett Bay Region	
New Hampshire Forest Resources Plan Revision	http://www.na.fs.fed.us/	http://www.na.fs.fed.us/sustainability/pubs/criteria/lessons_learned.pdf	August 2006	USDA – Forest Service	
An adaptive indicator framework for monitoring regional sustainable development: a case		http://sspp.proquest.com/archives/vol6iss1/0901-004.vanzeijl.pdf	June 2, 2010	Maastricht University, The Netherlands	

study of the INSURE project in Limburg, The Netherlands					
European Environment Agency	http://www.eea.europa.eu/	http://www.google.com/url?sa=t&source=web&cd=117&ved=0CD8QFjAGOG4&url=http%3A%2F%2Fwww.eea.europa.eu%2Fen%2Fpublications%2Ftopic_report_2003_1%2FTopic_1_2003_web.pdf&rct=j&q=indicator%20framework%20water&ei=-kunTaihBYK2sAOs3Kn6DA&usg=AFQjCNFVjxl-s4ADH841VPGij4E5aXoKAA&cad=rja	2003	The EU	
An Indicator System for Surface Water Quality in River Basins		http://repositorium.sdum.uminho.pt/bitstream/1822/4638/1/OLIVEIRA_CI1_2005.pdf	2005	Universidade do Minho, Portugal	Good to read to get sense of how to develop indicators
UN Indicators of sustainable development: framework and methodologies 2001, 2007		2007 version (last one) http://www.uneca.org/eca_programmes/sdd/events/Rio20/WorkshopSDIndicator/SustainableDevelopmentIndicators.pdf 2001 version	2007 April 2001	UN	1. Categories, indicators, methodology, evaluation per country, recommendations. 2. Application at national level 3. Discussion of

		http://www.un.org/esa/sustdev/csd/csd9_indi_bp3.pdf			different type of frameworks 4. Topics: health, poverty, governance, education, demographics, natural hazards, land, freshwater, atmosphere, ocean and coasts, biodiversity, economic development, global partnership, consumption and production patterns 5. Currently applying the new version in Africa
	UN Sustainable indicators for Africa	http://www.uneca.org/eca_programmes/sdd/events/Rio20/Workshop-Institutional-StrategicFrameworks/MerseiEjiguSDIndicatorsFrameworkforAfrica.pdf	2011	UN	Draft version for discussion
Indicator Frameworks for Assessing Irrigation Sustainability		http://www.clw.csiro.au/publications/technical2005/tr1-05.pdf	2005	CSIRO – Australian Research Institute	1. Include sustainability indicators based on system elements, system attributes and on a range of spatial scales 2. Presents different

					indicator frameworks for selection (i.e. state and control, driving force state response, TIM, AMOEBA) 3. Assess criteria for framework selection and assess frameworks
Water policy and reform framework in Australia	http://www.environment.gov.au/water/australia/coag.html National Water Quality Management Strategy http://www.environment.gov.au/water/publications/quality/index.html http://www.environment.gov.au/water/publications/environmental/index.html	** Most of the document links do not work in the main webpage http://www.environment.gov.au/water/publications/quality/pubs/water-quality-framework.pdf http://www.environment.gov.au/water/publications	2002 2009	Australian government	1. Different documents of principles, guidelines, objectives for water quality management. Some of them are more specific sub-frameworks with measures 2. Main topics: fresh and marine water, groundwater, diffuse and point sources, sewerage system, effluent management, water recycling 3. Water use prioritization

		/action/pubs/cehw-framework.pdf			framework, cooperative use
A National Framework for Improved Groundwater Management in Australia		http://www.environment.gov.au/water/publications/environmental/groundwater/pubs/framework-groundwater.pdf	1996	Australian government	Includes the main topics and indirectly presents indicators that should be defined for groundwater management
Conceptual Framework to Develop and Use Water Indicators		http://siteresources.worldbank.org/INTEEI/811099-1115809852605/20486439/ConceptualFrameworktoDevelopandUseWaterIndicators1999.pdf	1999	CIAT Colombia	Water indicators developed for two approaches: a project-based approach, and a Pressure-State-Impact-Response approach
Water framework directive (this is the framework for the whole EU)	http://www.water.org.uk/home/policy/water-framework-directive/about-wfd http://www.water.org.uk/home/policy/water-framework-directive http://www.doeni.gov.uk/niea/water-home/wfd.htm http://www.legislation.gov.uk/uksi/2003/3242/contents/made	http://www.water.org.uk/home/news/press-releases/sustainability-indicators-09-10/sustainability-2010-final.pdf http://www.doeni.gov.uk/niea/ams-report.pdf	2006 - 2010	UK	1. Webpage: aims, objective, strategy, timetable, milestones (However no specific pdfs of the framework itself) 2. Water sustainable indicator report for the UK

Swiss sustainable indicator system	http://www.bfs.admin.ch/bfs/portal/en/index/themen/21.html	http://inderscience.metapress.com/media/m3pnwhtyvral7xxuueet/contributions/x/k/0/5/xk0583543t853h57.pdf	2007	Switzerland	A paper that describes how the system was built, the development processes, selection of indicators and critical assessment
Minnesota Water Sustainability Framework	http://wrc.umn.edu/watersustainabilityframework/index.htm	http://wrc.umn.edu/prod/groups/cfans/@pub/@cfans/@wrc/documents/asset/cfans_asset_292471.pdf	2011	USA, University of Minnesota Water Resources center	Complete framework document, including environmental, social and economic components. Vision, objectives, Strategy, Outcomes, Measures of Success, and Benchmarks
Ecosystem Services Indicator Framework		http://www.esindicators.org/files/esid/Framework%20discussion%20for%20download.pdf			
Sacramento River Basin Report Card & Technical Report	http://ice.ucdavis.edu/waf/	http://ice.ucdavis.edu/waf/sites/ice.ucdavis.edu.waf/files/WHIP_TechRep_2010_0.pdf	2010	Sacramento River Watershed Program(SRWP)	Environmental Indicators for the Feather River Watershed
The State of the Great Central Valley of California Indicator Series	http://www.greatvalley.org/indicators/index.aspx	Multiple, see URL link	Ongoing, last in 2009	Great Valley Center	Economy, Environment, Community Well-Being, Public Health Access, and Education and Youth Preparedness.
State of the Sound	http://www.psp.wa.gov/	http://www.psp.wa.gov/downloads/SOS09/09-	2009	Puget Sound Partnership	Various ecological and human health

		04534-000_State_of_the_Sound-1.pdf			indicators.
The Index of Sustainable Economic Welfare	http://www.econ-pol.unisi.it/dipartimento/it/node/296	http://www.econ-pol.unisi.it/quaderni/449.pdf	2005	Università degli Studi di Siena, Italy	Economic evaluation like "gross domestic product"
Health-e-Waterways	http://www.health-e-waterways.org/		2009	University of Queenslands	environmental indicators (watersheds)
Chesapeake EcoCheck	http://www.eco-check.org/		2011	NOAA	Mostly environmental (water quality) indicators

related to the topic of sustainable water management but there were no detailed frameworks.

EUWARENESS - research project on European Water Regimes and the Notion of a Sustainable Status	http://www.euwareness.nl/home/	http://www.euwareness.nl/methodology/Applied%20methodology.pdf http://www.euwareness.nl/methodology/Scientific%20and%20socio-economic%20objectives.pdf http://www.euwareness.nl/summary/Background%20of%20the%20EUWARENESS-project.pdf		EU Commission University of Twente in the Netherlands.	1. Methodology and case studies 2. Scientific and social objectives
B-Sustainable is a project of Sustainable Seattle	http://www.b-sustainable.org/about-the-b-sustainable-project	http://www.b-sustainable.org/about-the-indicators-framework	Started 1993, continuously	Sustainable Seattle	1. A webpage including the history, development and indicators for natural,

			updated		built, social, personal environment goals

Appendix D Draft Sustainability Indicators

The following table lists draft sustainability indicators corresponding to each sustainability objective. To select indicators, 42 sustainability indicator systems (Appendix C) containing >1,800 indicators were reviewed for their potential use in this Framework.

California Water Sustainability Indicators Framework

Sustainability Objective	Related objectives and resource management strategies (from CWP)	Candidate Indicators	Data types, units	Potential data sources
1. Improve water use efficiency and water conservation in order to improve water supply reliability, reduce energy demand, and restore and maintain aquatic ecosystems and processes.	CWP Objective 2, 9; RMS Reduce demand			
		energy required per unit of clean drinking water delivered	Electrical energy (kWh/MG, % total energy demand)	CEC
		energy required per unit of irrigation water delivered	Electrical energy (kWh/MG, % total energy demand)	CEC
		adoption of greywater/reuse systems as standard for new construction	Standard adoption, quality of standards	

		Percentage of groundwater management areas that contain at least one over-allocated unit	Percent of basins, size of basins	DWR
		volume of water re-used (same volume can count more than once) as a fraction of total water used, including onsite, or recycled at a plant	Proportion and total water re-used locally and regionally	DWR, IRWM, water districts
		average water use per household,/capita, 20% reduction by 2020	G/capita	DWR, local water districts
		average water use per kg of edible agricultural product	G/kg	
		sufficient flows and timing of flows for maintaining historically-present native fish	volume and depth needed (cfs, m)	
		sufficient flows and timing of managed system flows suitable for native riparian habitats	Hydrograph peak(s)	
		timing of managed system flows suitable for native aquatic fauna	Hydrograph peak(s)	
		Quantity and timing of managed flows support natural geomorphic	Volume needed for process (cfs), hydrograph peak(s)	

		processes		
2. Improve regional water movement operations and efficiency and investigate new water technologies to contribute to social and ecological beneficial uses and reduce impacts to the Delta.	CWP Objective 1, 2, 7, 11, RMS Operational efficiency			
		annualized risk, over the next 20 years, of water shortage, calculated using up-to-date forecasts of precip, evapotrans, streamflow		
		distance traveled for units of drinking and irrigation water		
		infrastructure reliability: volume and proportion of water that is produced but undelivered because of leaky, broken, or otherwise dysfunctional infrastructure		

		prevalence of pricing structures that incentivize water suppliers to promote conservation, e.g. infrastructure paid for by hookup fees		
3. Increase conjunctive management of new and recycled water from multiple sources to increase quantity, quality, and reliability of drinking water.	CWP Objective 3, 12, 13; RMS Increase water supply			
		average distance traveled for drinking water		
		Percentage of irrigated ar ea that is in Water Stresse d Areas		
		net recharge or withdrawals		
		% of area in state covered by enforceable comprehensive groundwater management plans		

4. Protect and restore surface water and groundwater quality and the natural systems that maintain these services in order to safeguard human and environmental health and secure California water supplies.	CWP Objective 4; RMS on water quality; chapter 4 discussion of water quality sustainability indicators			
		Surface water Water Quality Index		
		Annual withdrawal of surface water as percent of renewable water		
		Total annual nutrient loading from municipal wastewater discharge		
		Attached aquatic plant cover		
		Mercury in fish tissue		
		Benthic macroinvertebrate community metrics		
		Ratio of observed to expected native aquatic species		
		Number species at risk (threatened & endangered)		

		Carlson's Trophic State Index (for lakes)		
		Index of biotic integrity		
		Fish assemblage integrity index (FAII)		
		Groundwater Water Quality Index		
		Percent of wells that exceed at least one maximum acceptable concentration (MAC)		
		Number of wastewater permit violations		
		Septic system compliance trends		
		Number of acres protected or enhanced in aquifer recharge areas		
5. Practice, promote, improve, and expand environmental stewardship to protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes.	(CWP Objective 5, 12, 13; RMS Natural Resources)			
		Number of hectares under conservation agreement per watershed unit-area	hectares	State records, GreenInfo Protected

				Lands database
		Participation rates by the local stakeholders such as municipalities, indigenous people, irrigation districts, community organizations, watershed associations, conservation groups, and stewardship groups	percent participation per group	internet research/ survey/ interviews
		Scope of recommendations and key actions that are developed during the planning process	good range of recommendations encompassing env. Stewardship	Workshop/ end of planning phase review
		Number of newsletters, workshops, watershed tours, and local media stories about the planning process	# publications	internet research
		Percentage of key stewardship and water conservation actions that are implemented both during and after the process	Analysis of implementation	workshop / end of planning phase review
		Stakeholder acceptance and support for planning upon completion of the planning phase	Expert opinion	Workshop/ end of planning phase survey

		Public awareness of source water protection issues	Survey data - scale	Survey
		People that have positive environmental attitudes in the region	Survey data - scale	Survey
		People's level of satisfaction with the level of the region's environment	Survey data - scale	Survey
		People's level of support or opposition to environmental regulations	Survey data - scale	Survey
		Percentage of people taking regular public actions to support the environment	Survey data	Survey
		Annual volunteer rates (% of population)	Survey Data	Survey
		Annual donation rates (% of population)	Survey Data	Survey
		voter turnout rate for environmental measures (% of population)	Survey Data	Survey
		proportion of streams monitored periodically for streamflow, temperature, fisheries, stability.		

6. Integrate flood risk management with other water and land management and restoration activities.	CWP Objective 1, 6, 12, 13; RMS Improve flood			
		Proportion of new construction with reduced paved surface and water conservation	% new construction	
		Proportion of floodplain per reach in conservation	% floodplain area	
7. Improve and expand monitoring, data management, and analysis to support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water management systems	New objective derived from conversations in CWP committees and meetings			
		Historical Benchmarks	Number/ threshold	depends on the data type
		Data sharing and distribution among disparate entities	Reference from implementation plans	
		Data standardization among disparate entities	methods	Evident in plans
		Minimize collection biases across entities	methods	Evident in plans
		Communication of uncertainty	plus/minus, error bars, significance	Evident in plans

			reporting	
		Describe data collection methods	text	Evident in plans
		Ease/feasibility of data collection and management	methods	Expert opinion
		Relevance and applicability for policy and management	text	workshop/end of planning phase review
		Spatial scale of data collection, relative to decision-making	numerical	Expert opinion
		Temporal scale of data collection, relative to decision-making	numerical	Expert opinion
		Collaboration between scientists and policy makers to understand data and communication needs	action	workshop / end of planning phase review
		accessibility of data to many entities		
		use of data - who, where, what, when…		
		supports adaptation and resilience to climate change		
		quantitative targets set for water and watershed goals		

Description of Indicators

The indicators below are organized by “sustainability objective” and are examples of indicators appropriate for each objective. The indicators and their component metrics were drawn from existing indicator frameworks that deal with water management, water quality, watersheds, regional sustainability, and ecosystem health. It is a list of indicators so far, not all possible or even best indicators. Each indicator (in bold) is followed by a short description of how the indicator contributes to the objective and measuring sustainability as a whole.

Sustainability Objectives

1) “*Improve water use efficiency, increase water recycling, and increase water conservation in order to improve water supply reliability, reduce energy demand, and restore and maintain aquatic ecosystems and processes*.”

<u>Example indicators:</u>

Energy required per unit of clean drinking water delivered
Managing, treating, and delivering water all requires electrical and other forms of energy. This indicator provides a measure of the energy demand associated with providing drinking water. The California Energy Commission and local entities (e.g., Napa County) have been studying the connection between water and energy in order to make both energy and water delivery more efficient and to conserve both.

Volume of water re-used (same volume can count more than once) as a fraction of total water used, including onsite, or recycled
Re-using water is a useful conservation strategy. Many water districts and other public works agencies are building recycling and re-use infrastructure to reduce the cost and impacts of “new water” use.

Average water use /household, or /capita, 20% reduction by 2020
By order of former governor Schwarzenegger, California agencies were instructed to develop a strategy to reduce California’s water consumption 20% by the year 2020. This indicator was used by the Los Angeles San Gabriel Rivers Watershed Council in its recent regional report card project, funded by CALFED/DWR.

Sufficient flows and timing of flows for maintaining historically-present native fish
Native fish, including anadromous species, need in-stream water to complete life-cycles, forage, disperse, seek thermal refuge, and escape predation. These flows must also be at appropriate times of day, year and season to allow them to function naturally. This is a common aquatic ecosystem indicator in managed water systems.

Magnitude and timing of managed system flows suitable for native riparian habitats
Streams and rivers support riparian vegetation, a specialized assemblage of plants that is adapted to and relies upon certain ranges of geomorphic and flow conditions. For example, natural cottonwood tree recruitment occurs when there is a gradual decline in the relative elevation of a river and its associated hyporrheic flow, but not if the decline is too rapid, as can accompany managed systems. This indicator is used in the Sacramento River Riparian Monitoring and Assessment Program, as well as other similar large-river systems.

Quantity and timing of managed flows support natural geomorphic processes
Movement and re-distribution of sediment downstream, channel migration, bank erosion, and new land formation are all important functions of in-stream flows. These geomorphic processes are supported above certain flows in a natural system and can be mimicked to some degree in managed systems. This indicator is used in the Sacramento River Riparian Monitoring and Assessment Program, as well as other similar large-river systems.

2) "*Improve regional water movement operations and efficiency and investigate new water technologies to contribute to social and ecological beneficial uses and reduce impacts to the Delta*."

Example indicator:

Distance traveled for units of drinking and irrigation water
Transporting water long distances results in energy, environmental, and water volume costs. Sustainable water management in California is likely to involve greater reliance on local/regional-sourced water.

Infrastructure reliability: volume and proportion of water that is produced but undelivered because of leaky, broken, or otherwise dysfunctional infrastructure
Loss of water to infrastructure inadequacies is inevitable in an aging system and affects the ability of water agencies and California as a whole to conserve water.

3) "*Increase conjunctive management of new and recycled water from multiple sources to increase quantity, quality, and reliability of drinking water*."

Example indicator:

Percentage of Irrigated area that is in Water Stressed Areas
Water availability for agriculture and drinking water is affected by historic use of limited water reserves (e.g., aquifers) and climate change. Reduced availability can result in water stress and water scarcity. Water availability in turn affects sustainability of related and natural systems. Irrigation in water stressed areas may be both necessary, because of

natural thermal and hydrologic conditions, and have negative consequences on future water availability. As water stressed areas expands in the future due to land-use and climate change, irrigated agriculture in these areas is likely to be affected.

Net recharge or withdrawals
Groundwater withdrawals and recharge are an essential part of California's interaction with groundwater as a resource for economic activities and health. How these occur and the net change in groundwater availability changes the future sustainability of California. In a project in the Napa watershed, led by Napa County, statistically significant decline in a groundwater basin was an important indicator of sustainable water availability.

% of area in region and state covered by enforceable comprehensive groundwater management plans

4) "*Protect and restore surface water and groundwater quality and the natural systems that maintain these services in order to safeguard human and environmental health and secure California water supplies*."

<u>Example indicator:</u>

Surface water, Water Quality Index
Various agencies, states, and countries have developed water quality indices composed of multiple metrics. They tend to include physical and chemical parameters and sometimes biological parameters.

Attached aquatic plant cover
Attached vascular plants and algae are a natural part of ecosystems. Increased light availability, water temperature, and nutrient availability can contribute individually and collectively to the over-growth of aquatic plants. This bioassessment indicator has become more prevalent among water quality agencies because it reflects a combination of effects of land and water use on aquatic ecosystems.

Benthic macroinvertebrate community metrics
Similar to aquatic plants, benthic macroinvertebrate (BMI) communities provide a measure of disturbance to aquatic ecosystem. There are a number of different BMI community metrics that are useful for understanding disturbance of stream ecosystems that are commonly used around the world and the California Department of Fish and Game. The Sacramento River Watershed Program and Napa Watershed indicators projects both included BMI metrics.

Ratio of observed to expected native aquatic species

An intact and healthy watershed and waterway network will tend to maintain most or all of the expected native aquatic fauna and flora over any one study period. As disturbance increases, fewer native species will be observed and this ratio will decline.

Carlson's Trophic State Index (for lakes)
This indicator is based upon measured Secchi depths in lakes. These depths are used to calculate algal biomass and phosphorous concentrations to estimate relative trophic state (e.g., oligotrophic) of lakes in a region, where primary production is associated with suspended algae and little non-algal turbidity is present.

Groundwater Water Quality Index
As with surface waters, various entities have developed water quality indices composed of multiple metrics for groundwater quality. The metrics tend to include physical and chemical parameters and sometimes micro-biological parameters.

Number of acres protected or enhanced in aquifer recharge areas
Protecting and enhancing the recharge potential (i.e., permeability) of lands appropriate for aquifer recharge will tend to expand available water supplies. Enhancement is generally a restoration to a natural state of permeability in an area with highly permeable soils and geology.

Percent of wells that exceed at least one maximum acceptable concentration (MAC)
There are legal thresholds for many drinking water constituents that are potentially present in groundwater. This indicator provides information at a municipal or regional scale about groundwater quality and contamination.

5) "*Practice, promote, improve, and expand environmental stewardship to protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes*."

<u>Example indicator:</u>

Number of hectares under conservation agreement per watershed unit-area
An important component of stewarding and protecting landscapes and watersheds is to enroll them in conservation programs using agreements and/or payments. Area, or proportion of watershed area, under conservation agreement is a common indicator of stewardship.

Participation rates by the local stakeholders such as municipalities, indigenous people, irrigation districts, community organizations, watershed associations, conservation groups, and stewardship groups
Social science tells us that participation in stewardship planning and decision-making among diverse parties is important in developing common and politically-supported

strategies and implementation. Rates of diverse party participation help predict likely successes or failures of processes at different scales.

Percentage of key stewardship and water conservation actions that are implemented both during and after the process
Actually carrying out stewardship actions is an important component of successful stewardship planning. This measure does not provide information about the ecological or social outcomes of the actions, but does take the first step of accounting for actions taken.

a. Percentage of people taking regular public actions to support the environment
A common practice among sustainability indicator systems is to measure public support for environmental protection. This can be measured in several ways, including b and c below. When people take action, they are demonstrably supporting environmental protection.

b. People that have positive environmental attitudes in the region
Support for actions by public agencies to steward and protect environmental conditions is based upon public attitudes toward the environment. When the public are supportive of these kinds of actions, then public agencies can more readily expend effort and resources on carrying them out.

c. Voter turnout rate for environmental measures (% of population)
When voters show up to support (or disapprove) environmental measures, they are consciously changing public direction and potentially charging themselves through taxation or fees. When votes are for environmental measures, this is a direct measure of public support for stewardship and protection.

Proportion of streams monitored periodically for streamflow, temperature, fisheries, stability
It is easier to manage what we understand. Monitoring conditions is critical to understanding how to protect natural systems. High rates of monitoring by public agency, or private organization programs suggest a high level of care and support for stewardship. It also leads to a greater understanding of the locations for stewardship need and the effectiveness of actions.

6) "*Integrate flood risk management with other water and land management and restoration activities.*"

<u>Example indicator:</u>

Proportion of new construction with reduced paved surface and water conservation
As the developed, impermeable surface area in a watershed increases, so does the risk of downstream flooding and channel incision. By constructing new roads, houses, and other rural and urban development with high permeability rates, risk of flooding can be

decreased. Conserving water may influence both water intake from surface and ground water locations and wastewater discharge. These changes and accompanying changes in management of the water path may change flood risk.

Proportion of floodplain per reach in conservation
Conserving and restoring floodplains can have profound effects on the risk and effects of flooding, depending on the proportion of the historic or contemporary floodplain that is affected.

7) "*Improve and expand monitoring, data management, and analysis to support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water management systems*." (new objective)

This objective is proposed to complement the other sustainability objectives that are based primarily on CWP-2009 Objectives and Resource Management Strategies. It deals with measuring whether or not the science and management systems themselves are responsive to existing and changing conditions. It supports the idea that sustainability is a process, as well as the result of a series of conscious actions.

Example indicator:

Data standardization, sharing and distribution among disparate entities
A common problem in synthesizing data to measure performance of complex systems is the lack of data format and data collection standardization among entities, even for common metrics. There is a similar lack in data sharing, sometimes within entities. A large agency, group of agencies, or more diverse partnership is more likely to understand, predict changes, and be able to sustain complex systems if basic data standardization and sharing protocols are developed and followed.

Communication of uncertainty
One predictable outcome of increasingly constrained managed systems and climate change effects is an increase in the uncertainty of predictions of how these systems will function. It is important for scientists and analysts to communicate this uncertainty so that it becomes useful information in management decision-making and policy formulation. This indicator refers to both the act of communication and the nature and content of communication. In other words, just narrative descriptions of uncertainty may be an insufficient level of information for many types of management decision-making, but may be sufficient to build responsive policies.

Ease/feasibility of data collection and management
Monitoring sustainability is most easily done when metrics and indicators are readily evaluated. This is made easier when data are easily collected and managed. When

systems are created to facilitate data processing, it is more likely that management will be based upon these data.

Relevance and applicability for policy and management
Management in support of sustainability is best supported by indicators and indicator systems that seem relevant to the management decision-making process. This may be because of familiarity (legacy of education), education about the indicators, or simplicity of the connections between the indicator and the decisions to be reached.

Spatial-temporal scale of data collection and management, relative to decision-making
Original collection and organization of data, or flexible organization of data, makes it easier to support decision with these data. Resolving data scale mis-matches with decisions can be accomplished with various statistical and other modeling approaches.

System supports adaptation and resilience to climate change
In order to allow for instantaneous and anticipatory responses to climate change effects, both the decision-making and information collection/analysis process should be designed to be flexible and adaptive to new conditions.

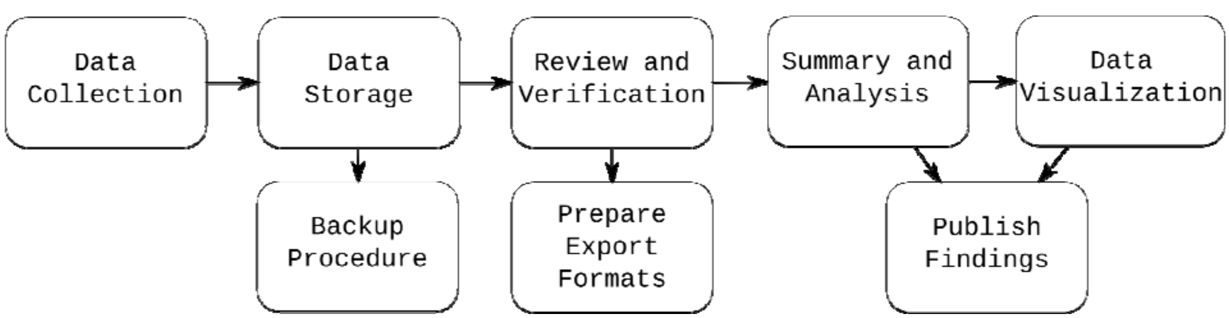
Quantitative targets set for water and watershed goals
When explicit and broadly-held goals are set for water and the natural systems that provide it (e.g., watersheds), then it is more likely that data collection and analysis can support decisions based upon those goals.

Appendix E Scientific Workflows

Scientific workflows offer both a theoretical as well as a practical way for building a comprehensive environment for data management, analysis, and decision support. Scientific workflows combine scientific data and process workflows, and provide a graphical interface to manage the pipeline of steps of a scientific problem (Ludäscher et al 2009). One can think of scientific workflows as similar to a flowchart, where the various nodes represent computational tasks and the lines connecting each step are the data inputs and outputs for each step. Each step can either be automated, such as a number crunching analytical task, or semi-automated, where external input and responses are required to complete the steps. A graphical interface allows for the chaining of the these tasks by managing the input and output of data between processes (Davidson et al, 2007).

Flowcharts are used in every industry to diagram process or business workflow. These illustrations are an excellent way of educating people about system processes, and they also provide excellent reference material for training and documentation. They can also be used to ensure certain steps are not omitted during a series of repetitive steps. While business workflows are based on business processes, scientific workflows are driven by data, and manage the data inputs, outputs, and transformations at various stages of the workflow (Bowers and Ludäscher, 2005). End-to-end data management practices can be incorporated into a scientific workflows, including data collection, storage, backup, retrieval, and analysis, and visualization. This explicit handling of the data management activities ensures that processes can easily be duplicated, and since it is a working workflow diagram, each step can also be well documented.

Scientific workflows provide an overview of the scientific problem broken down into its tasks and subtasks. From the data collection phase to data visualizations, a scientific workflow conveys these steps to the researcher so that each task in the process to each a completion of the scientific problem is well documented (Howe et al., .2009).



Scientific workflows offer a different way of looking at computation and data management. In a traditional model, the programmer schedules the execution of the control flow, and the system executes the specified procedures and functions. In scientific workflows, data transfer drives the computation. When the processes are connected to form a larger system, an executor initiates the workflow, and the flow of data initiates the pipeline of singular and parallel computational processes.

Scientific workflows, like social networks, are directed graphs where the nodes represent discrete computational components or process workflow steps and the edges represent results (data) which become the input parameters of the next node. Scientific workflows can be fully automated computational graphs, or semi-automated graphs with user inputs and human-based processes added (Ludäscher et al 2006).

Data Provenance in Scientific Workflows

A prominent feature to scientific workflows is how data provenance can be captured within the workflow. Data provenance refers to the origin of data, how it is managed, and how it is used for decision support. Scientific workflows explicitly provide these provenance pathways as edges in the directed graph. Each edge represents data flow, which have certain attributes and constraints that link the processes together. These dependencies define the provenance of data within the system, as they explicitly define the state of the data before they are consumed by the next step in the process (Davidson and Freire, 2008).

Data can undergo numerous transformations before it is stored in a database or data warehouse. *Data lineage* is the process of tracking the evolution of data, from the time of collection to the time of long term storage (Widom 2005). *Data provenance* documents how data was transformed so that reconstructing the original version of the data is possible. Data models need to include both provenance and lineage information so that researchers can query these metadata to understand the history of a data.

Scientific workflows can also be a good tool for documenting the lineage of the data, within the system. The data lineage includes where it comes from, what it is used for, and how it is transformed, at the various stages of the workflow. At any point in the process, it should be possible to recreate the exact state of the data.

Scientific workflows organize computational tasks, similar to a computer program, but they provide a user interface that allows researches--not just computer programmers--to understand better the scientific processes and data transformations used to solve the problem. The scientific method calls for a transparent handling of data and analysis so that the research community can replicate experimental results. Scientific workflow provides an excellent delivery mechanism of these results, where the visualization of the findings is joined with the methods performed to acquire data.

Building an indicator framework with Scientific Workflows

Each environmental indicator within an indicator framework has its own data management requirements. The data sources of often disparate, the techniques to transform and analyze the data are unique, and the visualization of these data depends on the environmental phenomenon being analyzed. Essentially, each indicator has its own scientific workflow.

While each indicator is different, they share many similarities. Each needs to collected data for analytical processing which leads to a result that allows managing stakeholders a means to make decisions. This often involves a visualization (graph), a summary of recent trends, or a comparison with other similar indicators. Therefore, once a scientific workflow is developed for an indicator, there is a strong possibility that the core structure of the workflow can be reused. Each workflow would essentially become a template for other indicators which perform similar tasks.

The ability to examine the data provenance within an indicator framework is critical. If decisions are made based on a particular analysis, having the ability to trace back to the data transformation can help verify those decisions. This can ensure a level of transparency in the decision making process, which is essential for indicators where grades or ratings are assigned to an environmental condition.

Scientific workflow processes can be integrated with online mapping components. The Open Geospatial Consortium (OGC) Web Feature Service (WFS) can be linked to workflow processes so that the generation of maps, an excellent visualization tool for the environmental sciences, can integrate into the workflow (Best et al. 2007).

There are several software applications to develop scientific workflows, including Kepler, VisTrails, and Taverna Workbench. Kepler and Taverna are written in the Java programming language, while VisTrails is written in Python. While building scientific workflows is still the task of a data modeler or programmers, some of these tools are making it easier for data analysts and project managers to participate in the workflows construction. There is a strong indication that these applications will continue to develop, perhaps to the point where such workflows can be modified over the web by decision makers, and provide specific tools for decision support.

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Appendix F Ecosystem Services and Sustainability Indicators

What ecosystem services are

Nature provides multiple benefits, also called ecosystem services, to humans. These include tangible services such as food and resources – fish, crops and freshwater, but also other less recognizable benefits including flood protection, erosion regulation, water purification and spiritual and cultural fulfillment. All these services, directly or indirectly, contribute to human well-being (MEA, 2005).

There are debates in the scientific literature about appropriate theoretical constructs to capture the essential attributes of ecosystem processes, services, and benefits (figure 5), while making sure the constructs are accessible and useful to land managers, land-owners, and agencies (Boyd and Banzhaf, 2007; Fisher and Turner, 2008). Superficially, some of this debate may seem about semantics (e.g., is pollination an ecosystem service, or is the food production from pollination the service?). However, as Wallace (2007) points out, terminology and logical and intuitive frameworks are keys to operationalizing the accounting for and protection of ecosystem services.

Ecosystem services can be quantified in their native units (e.g., tons C sequestered), and evaluated on the basis of their separation from the "ideal point" (Malczewski, 1999). Thus service/benefit values are re-scaled by comparing to a desired measurable condition, as implied by objectives for the system.

Ecosystem services/benefits outcomes can also be aggregated and incorporated into an overall assessment of categorized services/benefits for a geographic reporting area. This step is not essential to quantifying services, but helps in evaluating progress toward goals and objectives, or aggregate value of an area of the landscape. Additive forms are one aggregation process, but is not the only one and not appropriate when services/ benefits are not independent (Keeney and Raiffa, 1976; Zeleny, 1982). In this case, the less restrictive weak-difference independence condition is necessary for multiplicative and multi-linear functions (Butler et al., 1997 & 2001; Thurston, 2001).

Consideration of ecosystem services in the Framework will be substantially based upon approaches and uncertainties identified as critical by the Millenium Ecosystem Assessment (2005). These include relationships between process and rivers across scales, the relative linearity of changes in ecosystem function in response to drivers, market and non-market valuation methods for services that can link ecosystem processes to benefits to people, modeling changes in services across likely landscape-scale scenarios, incorporation of human behavior to improve quantitative modeling and decision-support, cross-scale linking between services and (who) benefits, and effective communication with non-technical decision-makers. The MEA has much in common with more detailed ecosystem service evaluations in agricultural systems and in the West (figure 1).

Market opportunities exist for ecosystem services, often described as “payment for ecosystem service” (PES). PES programs are negotiated contracts with landowners to maintain a certain level of environmental performance to maintain or enhance ecosystem services (examples: Forest Trends and Ecosystem Marketplace, 2008). Developing ecosystem indicators and metrics and tracking project impacts using those measures can make it easier to access any operating regional ecosystem markets and if ecosystem markets are available and if metrics were developed, then system for ecosystem measurement should be well-suited to ecosystem market use.

Figure 1 Cross-walk among the Millennium Ecosystem Assessment (2005) ecosystem services categories and those from 3 recent evaluations of ecosystem services in global agriculture (Foley et al., 2005), Oregon’s Willamette Valley (Nelson et al., 2009), and California’s rangelands (Shaw et al., 2009).

Ecosystem markets present various benefits for infrastructure agencies:

- First, it removes the risk of uncertainty of the project linked to the needed approval by environmental agencies. Projects are often slowed or stopped by deficient environmental analysis like the Environmental Impact Report (EIR) required by federal and state laws: National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), or the Clean Water Act.
- Second, ecosystem markets include a transfer of liability: the liability for the restoration or conservation success is placed on the banker and not on the infrastructure agency.
- Third, this system produces a better alignment of mission since instead of water engineers, restoration professionals build the ecosystem service projects.

- Fourth, ecosystem market may produce improved ecosystem outcomes because bankers can have more comprehensive and meaningful projects to address ecosystem priorities.

But although PES systems have great potential power for ecosystem preservation, there are still major criticisms (Redford and Adams, 2009), including the risk that economic arguments about services valued by humans will overwrite and outweigh noneconomic justifications for conservation and the concern that there is no clear way to track the performance of the system. Therefore, ecosystem service markets must be only one of several tools aiming at preserving ecosystems.

All the major ecosystem services can be classified in four main categories according to the Economics of Ecosystems and Biodiversity (TEEB) system (Table 1):

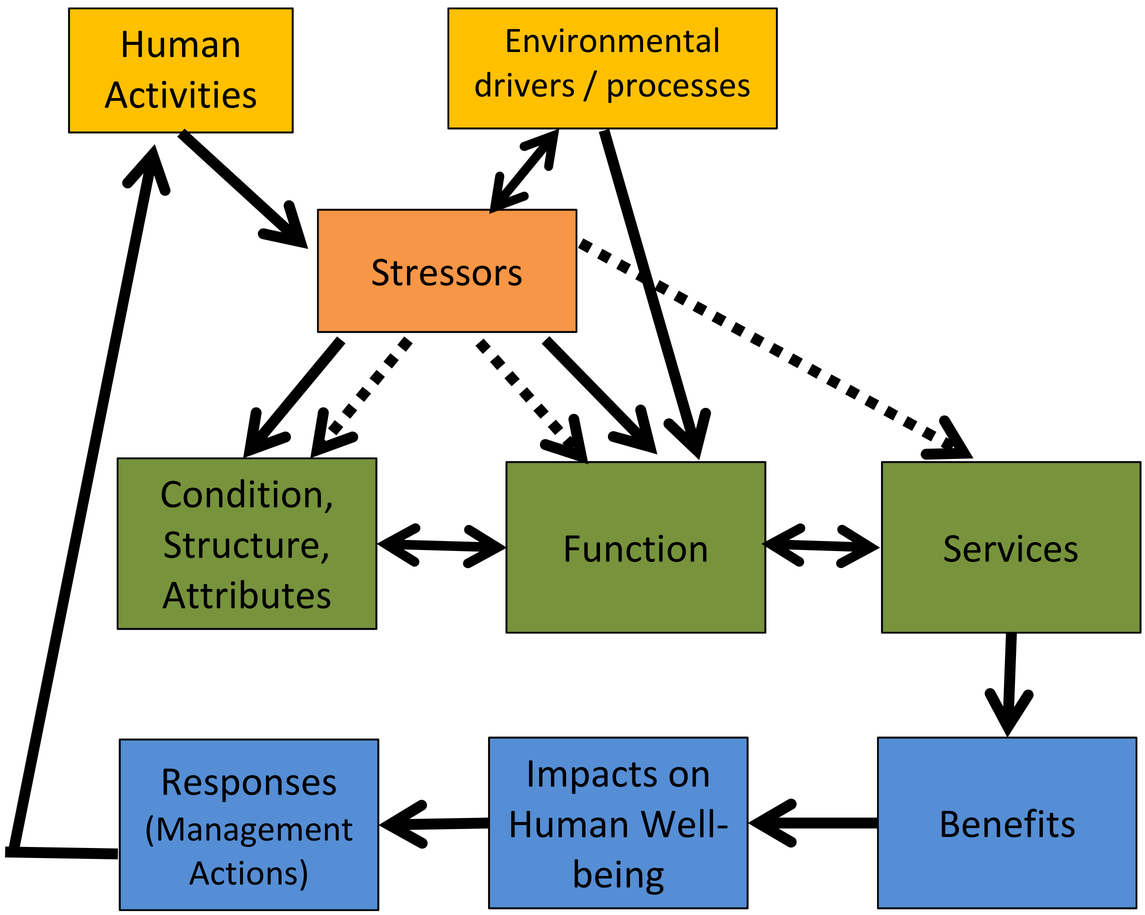
a. **Provisioning services:** the goods and products obtained from ecosystems, which include crops, timber, and livestock as well as genetic resources for medicines.
b. **Regulating services:** the benefits obtained from an ecosystem's control of natural processes, in other words, from maintaining a healthy functioning ecosystem. These include water regulation and climate regulation.
c. **Supporting services,** the natural processes that maintain other ecosystem services, including nutrient cycling, water cycling, primary productivity.
d. **Cultural services,** intangible and non-material benefits people derive from nature, such as spiritual and aesthetic benefits as well as recreation and tourism.

How ecosystem services are provided

Natural systems and their elements are highly interconnected. The water cycle represents a good example of how ecosystem structure and processes provide services and benefits to people (Wright and Johnson 2011). Water is found in diverse forms and locations (streams, atmosphere, groundwater), each having a specific structure defined by biotic and abiotic attributes. Various processes (precipitation) and external environmental drivers (climate, geology) act on this ecosystem structure and on its specific functions (infiltration) to make water available and to move through the system. This ecosystem functioning allows the flow of energy among biotic and abiotic elements and continuously provides ecosystem services. Humans derive benefits from the use of water through direct consumption, through its living resources or after enjoying aquatic recreation activities. Additionally, people also benefit indirectly from ecosystem processes including water flow regulation or water infiltration. However, humans also modify the condition of water, the landscape and the biodiversity found in natural systems, which has an effect on the ecosystem functions and the services associated with them. A negative impact on ecosystem services can lead to the promotion of management actions and responses, which could restore, maintain or enhance the structure, condition and function of the natural system and consequently the services that depend on them.

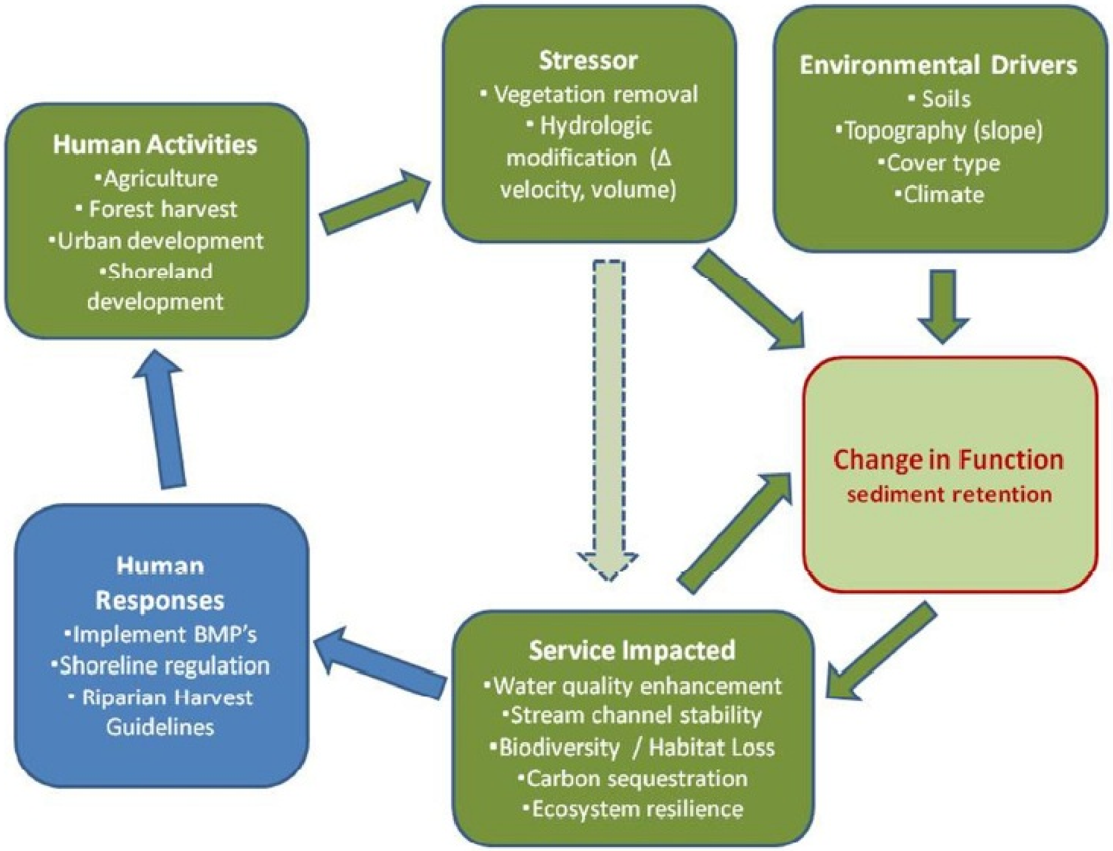
There are complex interactions which comprise ecosystem services (figure 1). The provision of ecosystem services involves complex dynamics and interactions among the different elements, processes and functions of the system. An ecosystem function can be associated to multiple services and the strength of these associations could vary depending on the system conditions and external influences. Figure 2 illustrates an example of these interactions related to sediment retention as an ecosystem function.

Figure 1. Model of ecosystem services provision



Based on Wright and Johnson 2011, UNEP-WCMC & WRI 2009

Figure 2. Sediment retention stressor-function-service-response diagram



Taken from (Wright and Johnson 2011).

Why indicators of ecosystem services are necessary

The Millennium Ecosystem Assessment, a worldwide study of the state of the world´s ecosystems, reported that 60 percent of ecosystem services were impacted and emphasized the importance of evaluating ecosystem services and the need to monitor them to achieve sustainable development (MEA 2005, Carpenter et al. 2009). In order to reverse current trends of ecosystem degradation and to become more sustainable, it is an urgent priority to integrate ecosystem service considerations into mainstream economic planning and development policy at all scales. Ecosystem service indicators can be used as tools for communicating the value and condition of ecosystem services to policy-makers and help them integrate this information with social and economic indicators.

How to integrate indicators into an ecosystem service framework

The goal of ecosystem service indicators is to inform about the characteristics and trends in ecosystem services. Ideally, these indicators should provide information about the *flow* of service— the benefits people receive (Layke 2009). However, indicators of flow of service are not always easy to implement due the difficulty in measuring the flow of benefits from some regulating and cultural services (Feld et al. 2007). Therefore, in some cases it is necessary to rely on proxy indicators, which are substitute measures when it is not possible to measure the service directly. In the context of ecosystem services, examples include the amount of nutrient removed from agricultural runoff by wetlands (as a measure for nutrient retention and water regulation), and number of people visiting natural areas (as a measure for spiritual services).

A key first step in the development of an indicator system to assess ecosystem services is choosing the framework or conceptual model that the system will be based on. As flow of service - represented by the actual flow of benefits derived from the ecosystem service- is the goal to be monitored, frameworks including benefit models should be preferred (Layke 2009). One example of this conceptual framework is the *Benefits Model Building on the Ecosystem Services Framework* (Balmfordet al.2008, figure 3). In this model, services directly enjoyed by people are identified as "benefits" while services that provide these benefits are termed "processes". In addition, benefits mostly include provisioning and cultural services while beneficial ecosystem processes include mostly regulating services (with water provisioning a notable exception). This example illustrates that there could be differences in interpretation and definition of the framework components when trying to measure benefits from ecosystem services. A conceptual framework for ecosystem services like the one included in Figure 1 differentiates between ecosystem processes, functions and services. However, when the objective is to operationalize the framework with indicators that are required to capture the flow of benefits derived from ecosystem services, the need to assess and clearly define these categories or components becomes more evident.

A team of experts working collaboratively on ecosystem service indicators since 2008 recommended a framework based on the following 5 components in order to identify flow of benefits and select indicators to measure them (UNEP WCMC& WRI 2009):

a. **Condition-Structure**: the ability of ecosystems to support ecosystem processes and deliver ecosystem services
b. **Function:** the processes by which ecosystems deliver services and benefits. Most regulating and supporting services can be ecosystem functions in this classification;
c. **Service:** ecosystem products that are important for supporting human well-being, but not directly consumed by people. For example, freshwater that is used for irrigation or aquaculture is classified as a service since the freshwater supports peoples' livelihoods but is not directly consumed;
d. **Benefit:** tangible products from ecosystems that humans directly consume. For example, fish produced by aquaculture would be classified as a benefit. Could be expressed in physical or value terms.
e. **Impact or Outcome:** indicators of the state of people's physical, economic, social, and spiritual well-being.

An example of the indicators proposed according to the UNEP- WCMC and WRI (2009) suggested framework is included in Table 2.

Current development of ecosystem services indicators

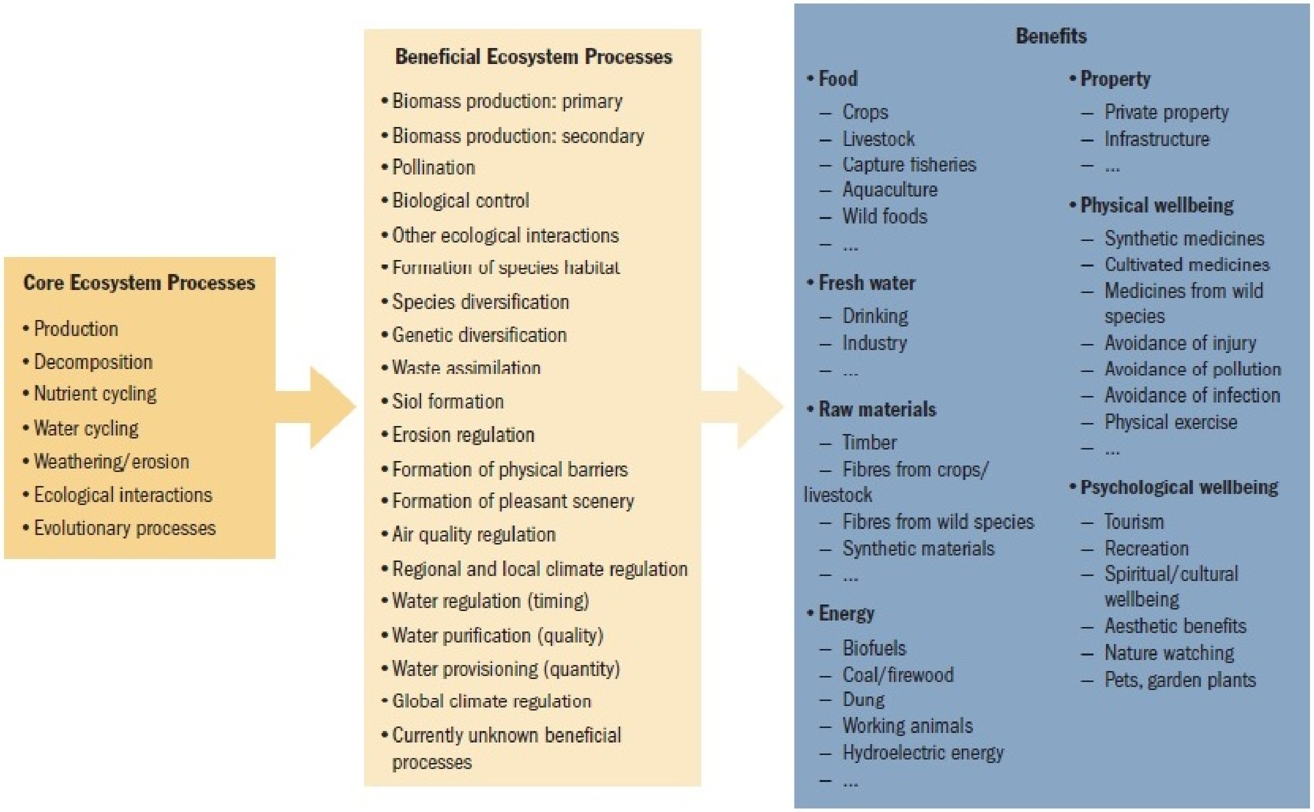
Ecosystem service indicators are relatively new tools to assess sustainable development. Frameworks, conceptual models and measures are being developed and evaluated for different topics, ecosystem elements and geographical areas. Two of the main issues that require further attention are finding the appropriate indicators that directly measure benefits flows and better understanding how indicators can adequately capture the interactions among system components and services. At the international level, there are currently efforts to develop and select indicators for ecosystem services and to compile an online ecosystem indicator database that can be used for policy-makers, resource managers and ecosystem assessment teams. The World Resources Institute (WRI) with the support of the UNEP World Conservation Monitoring Centre (UNP-WCMC) is leading these initiatives.

Table 1. The Economics of Ecosystems and Biodiversity (TEEB) classification of ecosystem services

Definition	**22 Service types**
Provisioning	1 - Food
	2 - Water
	3 - Raw Materials
	4 - Genetic resources
	5 - Medicinal resources
	6 - Ornamental resources
Regulating	7 - Air quality regulation
	8 - Climate regulation (including carbon sequestration)
	9 - Moderation of extreme events
	10 - Regulation of water flows
	11 - Waste treatment
	12 - Erosion prevention
	13 - Maintenance of soil fertility
	14 - Pollination
	15 - Biological control
Habitat/Supporting	16 – Maintenance of migratory species
	17 – Maintenance of genetic diversity
Cultural [provide opportunities for:]	18 - Aesthetic enjoyment
	19 - Recreation & tourism
	20 - Inspiration for culture, art & design
	21 - Spiritual experience
	22 - Cognitive development

Source: Groot et al 2009.

Figure 3.Benefits Model Building on the Ecosystem Services Framework



Source: Balmfordet al.2008

Table 2.Example of indicators proposed according to the UNEP WCMC and WRI (2009) suggested framework

	Condition	Function	Service (Use)	Benefit (expressed in physical or value terms)	Impact
SUPPORTING SERVICES					
Gene pool protection	Number of livestock breeds Number and share of (OR: Population size / percentage) of (native) livestock breeds that are endangered Number of crop varieties	Hectares of land in traditional varieties; Number of breeding females / animals within each species.		Number of disease resistant or tolerant livestock breeds or crop varieties	Avoided erosion of the genetic resource base Resistance to diseases
REGULATING SERVICES					
Climate regulation	Carbon stock (vegetation, soil, water bodies)	(Sustainable) net carbon storage/Net carbon storage (Tc/time unit); Net sequestration net balance between ecosystem carbon gains and losses, also size of stocks in vegetation, soil and water bodies.			Avoided economic damage, bodily harm, livelihood damage, etc. as a result of climate change mitigation

Source: UNEP WCMC & WRI 2009

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Appendix G Ecological and Water Footprint

An ecological footprint is a measure of the impact humans have on the earth. In the simplest terms, it is a measure of resource consumption and waste production compared with the planet's natural ability to generate new resources and absorb waste. An example of just one facet of an ecological footprint is the use of trees for construction or paper production. The use of trees not only results in extraction of wood/pulp in the form of logging of forests, energy use, and land use change, but also in the production of waste in the form of landfill pollution.

According to the Global Footprint Network, humanity's ecological footprint is greater than twice the size it was in 1966. With a footprint this large, societies on earth require more than 1.5 planets to support life as we know it. Furthermore, the earth's ability to regenerate the amount of material humanity uses in a year takes 50% longer than the time it takes to consume the same resources. It is projected that in 2030 our need for resources will equal two planet Earths to maintain our current rate of consumption. Although there are global estimates for humanity's overall ecological footprint, countries differ in their contributions, measured in terms of consumption and biological capacity (the ability to regenerate natural attributes). Under the ecological footprint system, the combination of consumption and biological capacity results in either an "ecological credit" or an "ecological debt" measure for each country. Most countries in the world are currently operating as ecological debtors, using more resources than can be replaced in the same amount of time (Global Footprint Network 2010). In fact, while humanity's demands have been rapidly increasing, many countries are outsourcing resources (World Wildlife Fund 2010).

The Water Footprint Network developed a global water footprint standard that contains definitions and calculation methods for determining water footprints for different purposes and scales. The assessment contains four steps: Setting goals and scope, water footprint accounting, water footprint sustainability assessment, and water footprint response formulation. There are different types of water footprints: the water footprint of a product, consumer, community, national consumption, business, and any geographic area. The level of detail needed for data as well as the frequency of measurements depends on the spatial scale assessed.

Without understanding the level of input vs. outputs in our water cycle, we cannot grasp if, as a society, we are prepared for future population growth and the needs of humanity. The WWF estimates that although 1.8 billion people in the world have access to internet, 1 billion still do not have access to freshwater (World Wildlife Fund 2010). It is important to link water use to indicators that are both internal to a region (e.g. agriculture, consumed goods, energy, and land use) as well as external (e.g. imported products and services that use water outside the region either directly or indirectly). The indicator framework provides indicators that will help California measure its water footprint and ecological footprint. Measurements of ecological integrity, flood risk, land use, pollution, recreation, groundwater, and cultural uses, in addition to water use and quality in both the short and long term all contribute to our overall understanding of the water footprint and by extension ecological footprint.